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Arkansas Plan for Licensing Water Works Operators

By W. R. Spencer

Prof. of Civ. Eng., Univ. of Arkansas, Fayetteville, Ark.

Presented on Oct. 19, 1944, at the Southwest Section Meeting, Austin, Tex.

ANY man who takes pride in his field of endeavor desires to stand well among his fellow men in the field. A man who has the responsibility of providing, day in and day out, year in and year out, an adequate supply of potable water must do his work thoroughly and well. His responsibility is great, his fund of information is highly technical and the execution of his services to the community requires that he be a diplomat as well as a skilled technician. It is only natural that he should desire to be recognized as a man with a profession.

It was as a result of this line of thinking that the membership of the Arkansas Water Works and Sewage Conference moved to establish a rating agency. This agency was to be authorized to provide a means of measuring each man's ability and providing a certificate as evidence to the public of the professional standing of each man so rated.

At the 1939 Arkansas Water Works and Sewage Conference a committee was authorized to prepare a plan which would achieve this aim and which would keep it on a voluntary basis.

The committee made an exhaustive study of licensing plans throughout the United States and from this study they prepared a plan adapted to the situation in Arkansas.

The important points of this plan are as follows: first, it is entirely voluntary; second, it encourages study and preparation; and third, growth in knowledge and experience is required to reach the higher grades.

Three grades of licenses were provided—Grades A, B and C. The grade to which an applicant could aspire was determined by his operating experience, the responsibility of positions held and his scholastic preparation.

There was no "grandfather clause" in the plan proposed. All applicants were required to furnish an experience

record and pass a comprehensive written examination. As an incentive to study, the examination questions were arranged for four divisions—Water Source and Pumping, Water Treatment, Distribution and Metering and Supervision and Finance.

With three grades of licenses and four divisions in each grade this provided for twelve examinations. Not more than four of these divisions were to be taken in any one year.

The examinations were to be held each year in connection with the Annual Water and Sewage Conference.

Each candidate would be required to furnish the secretary of the licensing board with complete information concerning his experience and scholastic training. The applicant would also be required to pay a fee of one dollar to pay for the cost of certification in case he qualified. The licensing board would be responsible for deciding on the grade of license for which each applicant would be examined.

The committee on licensing presented its report at the 1940 Annual Water and Sewage Conference. It was approved and adopted.

A five-member licensing board was then named and instructed to hold the first examinations in 1941. The committee prepared questions suitable for the twelve divisions and held the first licensing examination on the first day of the 1941 Conference. Thirty-one water works men took the examination at this time.

Examinations have been held each year. To date, 34 men have qualified for Grade A licenses; 23 of these have qualified in all four divisions. Twenty-nine men have qualified for Grade B licenses, and fifteen of these have qualified in all four divisions. Eleven men have qualified for Grade C licenses and five of these have qualified in all four divisions.

Many of the younger men for whom the plan offered the greatest advantage have joined the armed forces or gone into war industry. After the war it is hoped to hold regional schools or conferences to interest these young men in further study as an aid to practical experience in preparing for advancement in the water works field.

The voluntary licensing plan in Arkansas has a long way to go, but the interest and support of the men that make up the Arkansas Water and Sewage Conference is all that can be desired. Because of their interest and determination to secure professional recognition, we expect to develop an organization that, in time, will achieve this goal.

History and Purpose of the Certification Program in California

By K. W. Brown

Cons. Chem. Engr., San Francisco, Calif.

Presented on Oct. 28, 1943, at the California Section Meeting, Los Angeles, Calif.

IN considering the history and purpose of the certification program, it must be emphasized that certification in California applies only to the operators of water and sewage treatment plants. It does not apply to water works employees in general. Furthermore, certification is carried on on a purely voluntary basis and all operators, regardless of the type and extent of their water treatment experience, are eligible to participate.

Certification Plan

Definite action toward voluntary certification was initiated in the spring of 1936 when an announcement was sent out setting forth the procedure to follow and listing the requirements for each of the three grades of treatment plant operators. The classifications and qualifications then established are still in effect and read in part as follows:

Grade 1. All operators of a wide variety of treatment plants where chemical and laboratory control are involved. In this grade an applicant must be a graduate of a recognized college or university, having at least one year of experience as an operator and a degree in either sanitary, public health or chemical engineering. For a degree in civil engineering or chemistry the minimum experience requirement is two years, and for a bachelor's degree with courses in water chemistry an applicant must have no less than three years of experience. In lieu of a degree, two years of college training and five years of experience are acceptable. If education is high school or less, the experience requirement might be anywhere from five to ten years.

Grade 2. All operators of plants such as slow sand filtration, rapid sand filtration, water softening, iron removal, coagulation, chlorination other than by manually-operated chlorinators, ammoniation, algae treatment or taste and odor control. An applicant in this grade must be a graduate of a high school or its equivalent, having additional training in water chemistry or bacteriology and experience as an operator of at least two years.

Grade 3. All operators in the second grade but where the operators hold subordinate positions or are more or less on an apprentice basis. In addition, operators of simple aeration and manually-controlled chlorination equipment. There are no specific educational requirements for this grade but the minimum experience requirement is two years.

It was possible during 1936 to qualify for certification merely by filing an application form giving essential informa-

tion with respect to training and experience. Since then, however, an applicant is required to take oral and written examinations, arrangements for which are usually provided during the annual convention period of the California Section of the American Water Works Association. In 1943, however, because of travel restrictions and the inability of plant operators to find anyone to take their place during the time it takes to go to the convention, a plan was worked out whereby examinations were given at each of several locations in addition to the annual convention.

Nature of Examination

The examinations are relatively simple. Oral interviews consist for the most part of inquiring into information given on the application, while the written material consists of a number of true-or-false questions, together with three or four questions of the so-called "discussion" type. In connection with the written part, the committee this year has undertaken the job of assembling a list of suitable questions. These will be expanded as time goes on, ultimately reaching the proportion of a reservoir which can be drawn on whenever it becomes desirable to give a written examination for any one or all of the three grades. There will thus be no need for hasty or last-minute preparation and each applicant will be sure of receiving a similar and equally appropriate examination.

Certification Record

At the present time there are 168 certified operators, 34 of whom are Grade 1, 72 Grade 2, and 58 Grade 3. Of these certificates, 110 were issued in 1936 when the program was first started and prior to the time it became necessary to qualify by taking oral and written examinations. Hence, with an increase of only 54 in almost nine years, it might be assumed that most of the operators are already certified or those who are outside the fold have not been suitably and consistently informed regarding the desirability of participating in this program. It might also be assumed, of course, that these men have little interest in going to the trouble of preparing themselves for the required examination.

To achieve the ultimate objective, with the enactment of legislation looking to compulsory certification, it will be necessary to show virtually complete co-operation in the voluntary program and to stimulate in all quarters an active recognition of what certification means, not only to a plant operator but also to his employer.

Purpose of Certification

In any such undertaking as this there are bound to be a few skeptics—a few men who question the underlying purpose and who want to know how they themselves can expect to benefit. The answer, at least so far as certification is concerned, may be best expressed by quoting a resolution adopted in 1937 by the Board of Directors of the A.W.W.A., which reads as follows:

> The Board of Directors of the American Water Works Association, realizing the importance of efficient operation of water purification plants as a protection to public health, endorses licensing, certification, or some form of regulation of water purification plant operators and supervisors as a means of preventing the employment of incompetent personnel and assuring some continuity of employment of efficient personnel.

This resolution still stands. It expresses the situation clearly and con-

cisely and explains in itself why there is a gradually expanding interest in programs leading to either voluntary or compulsory certification of treatment plant operators. About half the states have provided means for licensing or certification, some of which are compulsory by law, and further developments can be expected as a postwar undertaking. With the impetus of Association support, it is reasonable to assume that the time is not far distant when certification will be compulsory in all states. When that time comes those operators who have participated in voluntary programs will undoubtedly be certified or licensed without having to take a new and possibly more formidable examination.

Benefits of Certification

For those who want to know what individual benefits might be forthcoming, there are several very good answers. Over a period of years, in any well-administered certification effort, there is bound to be a gradual improvement in the caliber of operating personnel and a greater appreciation by communities, as well as by utility management, of the responsibility attached to the delivery of a safe and palatable water supply. This, in turn, should lead to a higher standing in a professional sense, as well as to an opportunity to participate more widely in civic affairs and activities. And finally, which is really what counts in the ultimate analysis, the recognition brought about by properly regulated certification should lead to the payment of salaries commensurate with the degree of skill and training required for the carrying on of a function having a direct and vital bearing on community health and well being.

Why License Water Works Operators in Indiana?

By P. S. Sikes

Director, Bureau of Government Research, Indiana Univ., Bloomington, Ind.

Presented on Apr. 13, 1944, at the Indiana Section Meeting, Indianapolis, Ind.

LICENSING is a very old legal concept. It was highly developed in English law 200 years before our constitution was written. In Indiana state and local governments there is extensive use of licensing—dog licenses, drivers' licenses, marriage licenses, store licenses, doctors' licenses, teachers' licenses and many others. Regardless of what the real purpose or aim of a licensing law is, it must be predicated on the legal principle of promoting the general welfare. The immediate legal purpose may be, and sometimes is, to raise revenue, although it is more commonly regulatory.

Being regulatory in nature, licensing is commonly applied to occupations, trades, professions and activities of a private nature, or to persons not connected with the public service. On occasion, however, it is thought the general welfare will be promoted by licensing persons as a prerequisite to entry into the public service. The aim here is to secure better qualified and more efficient government personnel. Although there are persons not in government service who might be affected by water works operators' licensing, they are very decidedly in the minority. Since the major objective in a program of this sort is to secure better government personnel in one large area of government, it is closely related to another program commonly referred to as civil service or the merit system. These two programs have a common objective, and should both be considered in a discussion of this nature.

One important point which is often overlooked in public service positions of the kind under consideration, is that public employees are more than mere administrators of the law. They are more than mere servants of the public. In a very large measure, they are important factors in the determination of policies. Water works operators are the "experts" upon whom the legislative body depends for advice and information. Legislators cannot know the subject as well as the trained men they employ and are, consciously or unconsciously, guided by the operators' advice. This situation obtains, to a marked degree, in matters of public health and to some extent in every field of policy formation.

The most common distinguishing characteristic of the merit system is that of recruitment on the basis of predetermined qualifications as against appointment on the basis of politics or other extraneous factors without regard to ability. A true merit system, of course, involves much more than this. Not only should it secure employees of high caliber, a scientific classification of positions, an equitable pay plan and security of employment for efficient workers, but it should leave

a wide-open back door for ridding the service of inefficient and incapable employees. Under a good merit system there is no desire to take away from the executive or administrator his authority to do the appointing, or to remove the inefficient. A personnel department or civil service commission, rightly conceived, is only an aid—a helping and sympathetic hand—to the executive. Likewise it is a friend to the employee. The personnel department wants him to be happy, his morale to be high and the treatment he receives to be fair and impartial. In brief, the public should get efficient and intelligent service from a happy, contented but ambitious public servant.

Most people agree that good government, economically operated with efficient personnel, would be a desirable end, but they disagree on the methods of accomplishing this end. Those to whom we generally refer as the politicians cling to the spoils system for the patronage value of the system. They consider the public service jobs the "legal tender" with which large segments of votes are purchased. It was the late Senator Norris who said, "When a political party has nothing to keep it together except holding public office, the elements of death are already upon it." Whether members of the water works profession favor a merit system, licensing system or some other system, most will agree that in the field of water supply and in allied public health work "politics and bacteria do not mix in the public interest."

In somewhat general terms these are the principles that should be considered when one thinks of prescribed standards for water works operators. The greatest difficulty is in connection with administrative details of the system. The old civil service commission idea, under which an examination is given, eligibles certified and then the employee forgotten (unless there is an appeal for unlawful dismissal or a similar action), is comparatively simple and does not entail licensing. In a personnel system which services the appointing officers and serves the employees and, at the same time, safeguards the public interest, the problem becomes more complex. To mention only one point of difficulty, if the generally accepted principle to be followed is that the personnel agency or civil service commission should not have the power to "hire and fire," what assurance will we have that an inefficient employee will be dismissed by a locally elected, politically-minded appointing authority? The principle of the open back-door policy for the inefficient is just as important as the closed front door for the unqualified.

The bill that the Indiana Section supports, in common with the laws of several states, has the license feature or concept in it. In the background, the merit system involves the principle of protection of the public interest, but in the case of licensing, this principle is the very essence of the system. License in the field of governmental regulation may be defined as "authority to do some act or carry on some trade or business in its nature lawful but prohibited by statute, except with the permission of the civil authority, or which would otherwise be unlawful" (Bouvier).

Civil authorities in this country do not go about prohibiting "acts which in their nature are lawful." Indeed, such would be in violation of the "due process of law" provision of the Constitution, unless such regulations can be shown to be necessary to protect the public interest. The concept of licens-

ing is much older than that of the civil service or the merit system. It has been and is more widely used.

It has been found that where safety, health, morals, etc., are involved, the license suggests itself as a ready means of making administrative regulations more effective. In this respect the licensing system is superior to the merit system, at least as the latter has generally functioned. If the licensing authority has sufficient personnel to keep a check on the licensees, there is no reason why such an authority, through power of revocation and refusal to renew, cannot assure the public of faithful service by competent employees.

It should be remembered that the purpose of a vast majority of licensing laws is to regulate private activities in which there is held to be a paramount public interest. Hence the use of the licensing method for a group which is predominantly publicly employed must be justified on grounds different from those generally advanced in defense of licensing. A good parallel is the licensing of public school teachers. Licensing in this area may not appear to be as essential today as in earlier times, nevertheless, few of us are such strong advocates of local self-government or home rule as to feel that local trustees should be given complete freedom of choice in the selection of teachers. With licensing, we at least know that the teachers will have acquired certain minimum qualifications.

In the school system, in public libraries, in local public health departments and in the management and operation of water works and sewage systems, there is a paramountcy of state or general public interest which justifies a degree of supervision by the state at least to the extent of requiring competent personnel. It would be entirely possible to centralize the administration of any one of these functions, as has been done for some of them; or to have a state civil service or merit system with administrative or supervisory authority in local personnel matters. A greater number of states, however, have attempted to attain this objective through the licensing of public employees.

It may seem odd and incongruous to some people, especially those steeped in the traditions and virtues of personnel or merit systems, that government must license its own employees in order to get competent employees. We must bear in mind that, in the situation as it applies to water works personnel, the word "government" is an abstraction. To put it more concretely, there are four or five hundred separate governments involved. If there is to be a system, rather than many systems, of securing competent personnel, it must be a state system.

If all the water works operators in Indiana were employees of the state of Indiana, there would be no need for a licensing system. The better plan would be to extend the jurisdiction of the state merit system over these employees. It is doubtful whether a state-administered merit system would be feasible if applied to local employees. The alternative, it seems to me, is obvious. The best way in which the state may give to all the people of the state reasonable assurance that their water works operators will be qualified and competent is to inaugurate a good plan for licensing these operators.

Licensing Water and Sewage Plant Operators in Indiana

By Ralph B. Wiley

Head, School of Civ. Eng. and Eng. Mechanics, Purdue Univ., Lafayette, Ind.

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ON the basis of cost per capita for services rendered water purification and sewage treatment plants are relatively inexpensive; water is the cheapest commodity furnished to the public. Yet in the aggregate the total cost of these plants is not small and great savings in cost to the public can be secured or great losses avoided through their efficient operation by competent personnel. They are installed at the expense of the public to protect public water supplies and sources of supply and to insure a safe, wholesome water for domestic consumption. Faulty operation results in abuse of the plant and a consequent waste of public funds, but more significantly it endangers the public health.

Modern water purification plants will produce a safe and potable water when properly operated and they will remove hardness and iron—a great saving in the laundry—when designed for that purpose, but they are complex and require constant and careful operation. Incompetent operation can result in damage to expensive equipment. It is not uncommon to visit a water plant and find chemical feed apparatus out of order or maintaining improper dosages because of incompetent chemical control or to find automatic controls and meters out of service because no one knows how to adjust or repair them. In some cases the inexperienced operators are so ignorant of their duties that they consider some of the modern devices useless or a nuisance.

In sewage plants we find settling tanks foaming or clogged, green sludge being drawn from digestors, valuable sewage gas wasted, meters out of service, filter beds water-logged, siphons not functioning, and the plant so poorly operated as to produce an unnecessary nuisance, thus rendering the municipality liable to damage suits.

These plants must be properly operated 24 hours a day for 365 days in the year. The citizen knows immediately if the water pressure drops, but he cannot know that the water has suddenly become unsafe or that a sewage plant is discharging improperly treated sewage into the stream.

The Indiana State Board of Health tests samples periodically to check on operation, but it is impossible for its engineers to maintain a constant daily check. Its engineers cannot visit plants oftener than twice a year on the average. It is the duty of the operator to make his own chemical and bacteriological tests daily, and this requires skill obtained only by proper training and experience. Sudden fluctuations in volume or quality require immediate changes in operation.

In municipal plants it is not uncommon to find old employees replaced by political favorites. Inefficient, un-

trained and inexperienced men seek these jobs with every change in city administration. Licensing is not equivalent to civil service, but it will serve to insure that those discharged by the new administration will be replaced by competent men. Furthermore, licensing will protect the administration against the demands of politicians for the appointment of the inexperienced. It protects the public as well as the competent operator.

An objection often raised to licensing is that it requires another state board and more centralized control; it interferes with home rule in our cities. This is true, but the alternative is in too many cases no control, with the citizen the loser. Many states now have stringent licensing laws. Certainly it is more important to license such plant operators than it is to license barbers, beauty culturists, podiatrists, milk dealers, watch repairers, embalmers and funeral directors.

There would be no additional expense to the state in maintaining such a licensing board because the cost could be more than covered by the fees which the licensed operator would be glad to pay because of the protection it would give him from unfair competition by incompetents. The Engineers and Land Surveyors Licensing Board turns in money to the state general fund every year. It is operated at a profit to the state.

Purdue University, in co-operation with the Indiana State Board of Health, the Indiana Section of the American Water Works Association and the Indiana Sewage Works Association, has for some time held water works and sewage plant operators' schools. Under a licensing law these could and would be expanded, and the law would prove an incentive to energetic operators to attend and increase their competence. Thus local men can get the training necessary for competent operators. In addition Purdue University maintains an extension service to assist plant operators in solving their problems and in carrying on the experimental work frequently necessary to proper operation.

A suitable licensing law should provide for the appointment of a competent board composed of men of recognized experience in the field and free from political domination. The law should have teeth in it so that the board could compel obedience if necessary.

The licensing board should have power to classify the water supplies and sewage treatment plants of the state on the basis of the qualifications necessary in the responsible operating personnel of each plant, to examine applicants, to issue licenses to those of suitable proficiency in each class, to publish lists of those licensed in each class, to bring suit where necessary to enforce compliance with the law, to formulate rules for the rating of each plant and to revoke licenses when necessary.

The actions of the board should be a matter of public record.

The board would not have the power to dictate to the municipal administrations as to the appointment of particular operators. The municipal authorities should be free to choose their operators from the board's published list of licensees.

It would not be necessary nor even advisable to require licenses for all employees. Only those in responsible charge need to be licensed.

Such a law would be a protection to the public, to the municipal administration and to the competent operators in the state of Indiana.

Certification Program in Louisiana

By John H. O'Neill

Director, Div. of Public Health Eng., Louisiana State Board of Health, New Orleans, La.

Presented on Oct. 19, 1944, at the Southwest Section Meeting, Austin, Tex.

FOR various reasons it has not seemed advisable to sponsor legislation to require licensing of water works personnel in Louisiana. The Louisiana State Department of Health, however, has sponsored a program for certification of water department personnel which is of the so-called "voluntary" type.

At the 1939 meeting of the Conference on Water Supply and Sewerage a committee was appointed to consider the matter of certification of water department personnel. The committee reported to the 1940 meeting, recommending a program providing for the issuance of certificates by the conference on the recommendation of an examining board, following examination of applicants.

Three forms of certificates are issued namely, Classes A, B and C.

The examining board comprises a representative of the Louisiana State Board of Health, a representative of the College of Engineering of Louisiana State University, a representative of the State Department of Education, and two representatives of the conference. The examinations are held at the time of the annual short course at the university.

The first examination was held in 1941, and by agreement was limited to applicants for Class C certificates. Thirty-four men passed the first examination and were awarded certificates.

The examination for Class C is somewhat elementary but does cover the basic principles of water supply sanitation. It is divided into two parts, oral and written. The oral examination includes only a few questions and is in the nature of an interview with the applicant by one of the members of the examining board. The objective is to determine not merely the applicant's ability to answer the few questions, but also to evaluate his intelligence and his appreciation of the importance of water supply safety. For convenience, and to avoid difficulty for men who can not express themselves freely by writing, the written portion of the examination merely calls for checking statements made on the examination paper as "true" or "false."

The examination for Class B certificates is, of course, more difficult and includes questions on the theory and operation of water treatment processes, hydraulics and the maintenance of the distribution system.

The examination for Class A certificates is comprehensive and rather difficult.

In June 1942 examinations for Class B and Class C certificates were given. Thirteen applicants took the Class B examination and eleven passed. Two passed the Class C test.

In June 1943 the tests were given for Class A certificates for the first time. Nine took the examination and one passed. Two took Class B tests and one passed. Four took Class C and all passed.

In June 1944 six men took the Class A test and two passed. Nine took the Class B examination and five passed. Seven took the Class C test and all passed.

At the request of the Louisiana State Board of Health and the Conference on Water Supply and Sewerage, the Louisiana State Department of Education has employed an experienced man to teach water and sewer department employees. Prior to the war such instruction was given at district meetings. Due to tire and gasoline shortages, the instructor now visits individual towns and plants to give instruction to small groups, and thus is able to meet individual needs.

In several Louisiana communities classes are held regularly and instruction is given by the superintendent, manager or some of the employees.

Following this year's examination there was prepared and sent to all who took the examinations, a copy of the questions with answers thereto. It is planned to continue this procedure in the future.

Licensing and Training Water Plant Operators in Oklahoma

By Henry J. Darcey

State San. Engr., State Dept. of Health, Oklahoma City, Okla.

Presented on Oct. 19, 1944, at the Southwest Section Meeting, Austin, Tex.

THE licensing and training of water plant operators presents many problems, some of which are local in nature, while others are common to all states. It is because of the variations in conditions that different states have developed different training programs to serve best their needs.

The first short school for water plant operators and superintendents was held at the Oklahoma A. & M. College about 1922. Seventeen short courses had been held at the college up until 1941, when they were discontinued because of war conditions.

For a number of years the training program was confined to a period of one school week. In 1935, through the co-operation of the Trade-Industrial Division of the State Department of Education, the Oklahoma A. & M. College, and the Oklahoma State Health Department, the training program was expanded and, in addition to the one-week course, 24 district field conferences were held each year at various points in the state. The purpose of the one-day conference was to bring the training program closer to the people. It also permits many operators who were never able to leave their work, to attend a short course at Stillwater and to participate in the training program. These conferences proved very valuable, as they gave the governing bodies of the cities in which they were held a better idea of what was being done for their own employees and encouraged the operator's interest in his work.

When the one-day conferences were inaugurated, a definite program, covering a period of years for training the water and sewer department employees, was adopted. Part of the course was given during the annual short school, part was covered at the district conferences, and part was a local night course.

The program in general covered: (1) basic science courses, including mathematics, applied science, drawing, mapping and blueprinting; (2) technical courses, including accident prevention and first aid, elementary hydraulics, elementary electricity, elementary steam engineering, water and sewage bacteriology, principles of water purification, financial records, personnel relations, automotive transportation, principles of sewage treatment, corrosion, and algae and other fresh water life; (3) operations courses on water, including supply, power and pumping, filter plant operation, distribution system, selection, care and maintenance of equipment, standards and recommendations of fire inspection bureau, management, and rates and rate making; (4) operations courses

on sewers and sewage disposal, such as sewer systems, power and pumping, selection, care and maintenance of equipment, sewage plant operation and management.

During the development and presentation of this training program, there arose considerable interest in the matter of licensing water superintendents and operators, and it culminated in the introduction of a bill in the legislature requiring the examination and licensing of such personnel. After passing the Oklahoma House of Representatives, the bill failed to become law by lack of one vote in the Senate. Possibly, it was fortunate that the bill was defeated, for Oklahoma was really not ready for such legislation.

Later, a voluntary licensing program was recommended to the state health department by the Oklahoma Water and Sewage Conference, following which an examining board was appointed and several examinations were held. The examination questions were sent to the applicants for licenses, and they were permitted to use any text books or other sources of information except personal help. The papers had to be returned within a prescribed time, to be graded by the examining board. A number of licenses, effective for a two-year period, were issued as a result of these examinations.

Response to the voluntary licensing program did not develop as had been hoped, possibly due to the lack of a thorough understanding of the purpose of the program or to the lack of incentive for holding a license.

The action of the U.S. Public Health Service, requiring closer supervision over the water supplies used on interstate carriers, has focused the attention of the health department on the unsatisfactory features existing in many of these supplies which have received provisional certification over a period of years. In an effort to secure the removal of the defects so as to permit continued use of the supply, Oklahoma has decided to reward the city officials for their efforts to comply with the requirements for an approved supply by granting permission to erect "Approved Water Supply" signs on the main highways. One of the conditions which must be fulfilled by the city is the employment of a qualified superintendent in charge of the water system and treatment plant.

It is realized that this is a long-range program, requiring a training program for the superintendents and operators. In order to meet the need, plans are being made to initiate a small group or, if necessary, individual training programs, using a mobile laboratory and the services of district engineers. On completion of the training period, part of the examination will be given by the instructor. The examination will include, if possible, actual plant demonstration of the applicant's ability to operate his own plant, for the licenses issued will be good only for the plant the applicant is then operating and will be subject to renewal at prescribed intervals.

The effectiveness of such a training program will show little progress for several years, but over a period of years such a program will bring about an increase in trained superintendents and operators, which will be equivalent at least to the number of approved water supplies.

Licensing Water and Sewerage Works Operators in Texas

By C. H. Billings

Chief Asst. San. Engr., State Dept. of Health, Austin, Tex.

Presented on Oct. 19, 1944, at the Southwest Section Meeting, Austin, Tex.

THE licensing plan in Texas, as far as is known, was one of the first of its kind to be inaugurated. This plan had its beginning in 1933 following the presentation of a report of the Committee on Operation and Rating Standards of Water Supplies by Committee Chairman J. Bryan Miller, at the Fifteenth Texas Water Works Short School in Temple, Tex.

That report recommended the inauguration of a voluntary plan of licensing of water plant personnel by the Texas State Board of Health through the issuance of certificates of qualification. The committee also outlined suggested rules governing the licensing (most of which are in effect at the present date) and suggested three classifications—A, B and C—for the operators of the two types of supplies, well and surface.

The next step, consisting of the appointment of a qualification and rating board in January 1933 by the short school president, was taken with a view to setting up and placing in operation a method by which water supply operators could be licensed. The action taken by the board consisted of the final adoption of rules governing the licensing system, as well as establishing qualifications for three classes of licenses. Some Grade C licenses were actually issued during 1933, and, in January 1934, examinations were held for the Grade A and Grade B licenses.

According to the rules established by this board only water superintendents, water plant operators, laboratory directors, general managers of water companies, superintendents of distribution systems and sanitarians and sanitary engineers having experience in water supply work were considered eligible.

At the sixteenth annual short school in 1935, the board, feeling that its job of organization was completed, recommended that the plan of administration be placed under the state department of health. This resulted, however, in the appointment of a more or less permanent committee of the short school under the chairmanship of W. T. Gooch.

The Advisory Licensing Committee, as organized, prescribes the conditions under which the examinations are to be held, grades the examinations and approves the applications. Changes of major importance in the licensing program are not attempted by the committee but are reviewed with their recommendations and sent to the Executive Committee of the Texas Water Works Short School for final action. Under the present procedure of giving examinations, those for Grade C may be taken at the annual short school, before a member of the committee or

before the mayor of the city in question, and, if such arrangements are not practicable, in special instances, other officials can be authorized to supervise examinations. Grade B examinations may be taken before a member of the licensing committee, at the annual short school, or under an individual especially designated for that purpose by the committee. The Grade A examination may be taken only under the supervision of a member of the licensing committee or at the annual short school.

The procedure involves making application through the Texas State Department of Health to the Advisory Licensing Committee. Following approval of the application by the committee, the state department of health makes arrangements for the supervision of the examinations. The completed examinations are returned to the state department of health and from there forwarded to the committee for grading purposes. Thereafter the applicant is advised regarding his standing in the examination and a certificate is issued by the state health department after authorization by all of the members of the Advisory Licensing Committee.

Pursuant to many requests, in 1941 the Advisory Licensing Committee recommended broadening the scope of the licensing plan to include employees engaged in all phases of water supply operation. It provided further that the phases should be designated as administrative, production, control and distribution.

It was felt also by the committee that a need existed for including among the prerequisites for licenses a requirement in regard to training. For that reason, the committee recommended that the prerequisite qualifications include a certain number of hours credit for attendance at short schools and regional water works association meetings, the total number of hours to vary with the class of license. This plan went into effect in 1942 with the provision that the regional water works associations assist the licensing committee in reviewing the applications. This required a modified procedure in approving the application in that the application is first submitted to the regional water works association involved, which makes its recommendation to the Licensing Committee.

In 1943, a plan was adopted whereby the examinations would be more in line with the particular phase of water works operation with which the applicant is most familiar, that is, either administration, production, control or distribution. In line with this procedure, it was decided to indicate on the license certificate the phase or phases in which the applicant was examined. This plan is followed on Grades A and B licenses only.

The prerequisite qualifications for the various classes of license have been modified some during the eleven years in which the licensing program has been in operation. Some of these changes have been made necessary by wartime conditions. At the present time, however, the requirements for the different types of licenses may be briefly stated as follows:

Grade C. One year of water works operation experience and 20 hours of attendance obtained at Texas Annual Water Works Short Schools, district short schools, and special types of schools and district association meetings in which 20 hours of credit are allowed for annual water works short schools, and district short schools and two hours per meeting for attendance at district association meetings. The

credit allowed for other types of schools is usually actual attendance hours. In the absence of attendance hours, two additional years of experience may be substituted.

Grade B. Three years of experience in water works operation, and 80 hours of credit for attending short schools and district association meetings. A college degree in civil, chemical or sanitary engineering, or bacteriology or chemistry may be substituted for 40 of the 80 hours.

Grade A. Eight years of experience in water works operation and 120 attendance hours.

Of course, all applicants must pass a written examination. At the present time, the Grade C licenses are in effect for three years, the Grade B for five. The Grade A licenses do not require renewal. The Grade C and Grade B licenses may be renewed by making application and taking an examination.

In 1938, a similar program for sewerage system operators was placed in effect by the adoption of a resolution by the short school authorizing the appointment of a committee. The committee placed the sewerage system operators' certification program into operation during that year. This plan is very similar to the water works operators' plan in procedure, rules and manner of issuance of licenses.

Both voluntary programs have been very successful and have met with wide acclaim among the water and sewerage operators over the state. The state now has issued over 2,000 licenses to water works men, and 600 licenses to sewerage system operators. The licensed men represent the water and sewer departments of 379 Texas cities, with a total 1940 population of more than 2,700,000.

Although the present licensing system for water works operators is strictly voluntary, an effort has been made to tie it in very closely with the short school program of rating all public water supplies for approval by the state department of health. Under the rating system in effect, it is impossible for a public water supply to obtain approval without having licensed employees.

Since the inception of the program, legislation to put the voluntary plan on a legal basis has been suggested at many of the annual sessions of the short schools. This move has gained greater impetus during the past year under the leadership of the Capitol Area Water and Sanitation Association. Consideration is now being given by the Legislative Committee of the short school to the preparation of a bill for submission to the next session of the Legislature for this purpose.

In keeping with this move, the proposed Sanitary Code, which will likewise be submitted to the next session of the Legislature, has been written to include a provision that each water plant should be placed under the supervision of a competent water works operator who has been issued a license by the Texas State Department of Health.

Legalizing the licensing system has been proposed and encouraged by the water works men themselves and should they indicate their general approval, the state department of health is ready to fulfill its obligation. Recognition should be given, however, to those licenses now in effect and the incorporation into the new plan of a system of organization and procedure similar to that which has proved so successful under the voluntary program.

Recharge to Water-Bearing Formations Along the Ohio Valley

By Russell M. Jeffords

Geologist in Charge, Ground Water Investigations in West Virginia, U.S.G.S., Morgantown, W.Va.

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A SYSTEMATIC investigation of the ground water resources of West Virginia was begun in July 1941 by the West Virginia Geological Survey in co-operation with the U.S. Geological Survey. The purpose of the study is to collect and analyze data on the occurrence, quantity, quality and development of ground water in the state; to prepare for publication such information as would be of value to its citizens; and to assist individuals and state, federal and municipal groups in the solution of problems relating to water supplies from wells and springs (1).

Over practically all of West Virginia the surface is underlain by thick deposits of sedimentary rock. Many of the shallow sandstones, limestones and fractured shales yield potable water to springs and drilled wells. The thick sandstones and cavernous limestones occurring near the surface along the eastern border of the state give rise to springs that are used extensively for public and domestic water supply (2). In the central and western parts of the state, water-bearing rock formations are less numerous and may be underlain by saline brines at relatively shallow depths. However, small to moderate supplies of water can be obtained generally by means of drilled wells. Locally, excessive pumpage, coal mining, waste disposal and the migration of brines up oil and gas wells have affected adversely the quantity and quality of the available ground water supplies.

Superimposed on the consolidated sedimentary rocks there is commonly a veneer of soil and rock debris, which contains sufficient ground water to supply shallow dug wells. Along the major stream valleys occur relatively thick deposits of water-bearing alluvium that yield the greatest supplies of water to wells of any strata in the state. In the Ohio Valley these deposits average about 60 ft. in thickness and comprise an upper layer of silty clay underlain by moderately coarse sand and gravel. Equivalent deposits along the Teays Valley and the Monongahela, Kanawha and other streams are finer in texture and appreciably thinner.

About twenty public water works and numerous industrial plants along the Ohio Valley pump a total of more than 30 mil.gal. of water a day from these water-bearing formations. In recent years, however, difficulty has been encountered locally in obtaining additional amounts of ground water to supply new or expanding industries and the increasing population at industrial localities. Therefore, this

paper is a discussion of one of the most important factors affecting the yields of these wells—the determination and effect of recharge from the Ohio River.

Sources of Recharge

The major sources of recharge to the water-bearing alluvial formations along the upper Ohio River Valley are local precipitation and infiltration from the river.

In areas of little or no pumpage, the water table in these sand and gravel strata normally rises gradually away from the river. If the river bottom is not effectively sealed off by thick silt deposits, some ground water moves slowly into the river when the river is in pool stage. During periods of high river stage, however, the gradient may be reversed, and river water may flow into the gravel deposits. Similarly, when large quantities of water are pumped from wells, the water table may be lowered below the level of the water in the river so that river water can percolate into the water-bearing formation and can replace part of the water withdrawn. The amount of water that enters the aquifer from the river depends upon the difference in altitude of the ground water and river water levels, the area through which water is passing, the distance from this area to the well, the permeability of the intervening material and the temperature of the water.

Detailed pumping tests and other investigations at several places along the Ohio River Valley show conclusively that in some places these water-bearing strata receive a major portion of their recharge by infiltration from the adjacent river (3, 4 and 5). However, these investigations have shown that the complex character of the water-bearing formation and the erratic distribution of areas through which river recharge may occur make it unwise to apply factors of yield and source of recharge determined at one site to other seemingly similar sites even within half a mile.

Determination of the Sources of Recharge

Pumping Tests. The most reliable method of determining whether significant quantities of river water are recharging the water-bearing formations and, if so, the amount of recharge, is by means of detailed pumping tests, such as those conducted by the U.S. G.S. at the West Virginia Ordnance Works, Point Pleasant. Inasmuch as pumping tests may require the construction of numerous observation wells and an accurate measurement of the water pumped, they may be practical under conditions existing at many water works only in solving the more critical problems.

Water-Level Fluctuations. The relationship of fluctuations of the water levels in the river and in observation wells has been used to indicate the source of the water. However, interpretation of water-level fluctuation in wells requires a detailed knowledge of local conditions, as the water may be under slight artesian pressure so that relatively large rises in water level would not indicate necessarily the addition of significant quantities of river water.

Quality of Water. Studies made along the West Virginia section of the Ohio Valley indicate that tentative conclusions regarding the source of the water obtained from the alluvial sand and gravel strata can be made readily on the basis of the character of the water. The most diagnostic properties and constituents along the upper Ohio

TABLE 1

Analyses of Water From Alluvial Water-Bearing Formations and From Ohio River, in ppm.

Location	Depth, *ft.*	Diameter, *in.*	Yield, *gpm.*	Temperature, °F.	Date of Collection	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium and Potassium (Na + K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Total Dissolved Solids	Hardness, as $CaCO_3$ (a)		
																	Total	Carbonate	Noncarbonate
WATER FROM WELLS																			
Ravenswood	93	8	250	56	10– 7–42						136	12(b)	1.5	0.0	4.0		129(c)	112	17
Kent	96	6		53	4–17–42						312	24(b)	4.0	0.0	14		288(c)	256	32
Kaylong	69	156	1900	54	2–19–43	8.8	0.45	62	1.3	9.7	189	25	10			242	160	154	6
Pt. Pleasant	96	12	250	55	8–13–42						236	36(b)	8.0	0.2	4.1		213(c)	194	19
Lakin	90	8	70	58	8–13–42						174	20(b)	6.0	0.1	13		168(c)	143	25
Natrium	80	8	400		8– 4–42	10	0.16	69	5.8	4.4	168	28	4.2	0.1	28	250	196	138	58
Kaylong	75	156	2000	54	11–20–42	18	0.13	60	7.8	4.3	161	33	10	0.1	13	229	182	132	50
Glen Dale	100	8	125		11–19–43		0.22				200	76	15		6.9		189(c)	164	25
Beech Bottom	70	12	450	53	11–19–43						258	124	25		7.2		306(c)	212	94
McMechen	75	8	300		?– ?–41		0.0	124	18	41(a)	312	187	16				385	262	123
Wellsburg	80	24	500		11–19–43		1.3(d)				190	98	27		0.2		225(c)	156	69
McMechen	75	8	300	53	11–19–43		0.53				192	140	16		5.4		270(c)	157	113
Kaylong	65	156	2300	68	9– 2–43	9	0.2	61	7	12	115	76	26		0.2	259	181	94	87
Kaylong	73	156	2100	50	3–10–43	17	0.06	41	11	3.1	75	66	14			207	148	62	86
New Martinsville	52	240	700	52	4–15–42	16	0.01	57	7.1	17(a)	100	94	17	0.0	6.2	268	171	82	89
Paden City	92	12	500	55	4–14–42	16	0.01	30	5.5	15(a)	53	49	15	0.0	19	171	97	43	54
Follansbee	80	12	500		11–18–43		1.37(e)				84	109	21		1.8		159(c)	69	90
Parkersburg	50–65	18	50–300	53	5–27–42	13	0.11	47	8.4	17	72	93	19	0.2	1.8	241(f)	152	59	93
Parkersburg	50–65	18	50–300	49	3–11–42						66	112(b)	24		2.1		165(c)	54	111
Chester			500		11–18–43		0.13				86	169	35		2.5		210(c)	71	139
Moundsville	70	18	500		4–18–42	9.6	0.03	49	8.3	23(a)	58	116	24	0.0	4.7	250	156	48	108
WATER FROM OHIO RIVER																			
Benwood					4– 3–34			25	5.2	15	49	68	7			202	83	40	43
Cincinnati, O.					4– 32		0.5	21	3.8(a)	13(a)	29	53	12			133	68(c)	24	44
Sistersville					4–16–42						27	65(b)	7	0.0	3.8		64(c)	22	42
Kaylong					8– 9–44	10	0.2				39	104	51		4.0		154(c)	32	122
Cincinnati, O.					12– 30		0.3	60	12(a)	42(a)	52	144	70			407	200(c)	43	157
New Martinsville					4–15–42						9	75(b)	6	0.0	0.0		76(c)	7	69
Wheeling					7–19–32	6.0	0.06	30	6.6	16	8	105	13		2.3	188	102	7	95
Wheeling					9–11–34						3.7	191	22		0.03	338	113(c)	3	110
Martins Ferry, O.					9–11–34			40	10	21	3	187	20		0.5		141	2	139
Wheeling					9–11–34			40	10	24	3	184	19		0.4		141	2	139
Weirton					11–19–43			56	14	57(a)	3.7	264	31				196	3	193

(a) Calculated. (b) By turbidity. (c) Determined. (d) Includes 0.61 ppm. manganese. (e) Includes 1.3 ppm. manganese. (f) Includes 0.8 ppm. manganese.

TABLE 2

Analyses of Water From Alluvial Water-Bearing Formations and From Ohio River, in Percentages of the Sum of Equivalents per Million of Anions or Cations

No.	Location	Calcium (Ca)	Magnesium (Mg)	Sodium and Potassium (Na + K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride, Nitrate and Fluoride ($Cl + NO_3 + F$)
	Water From Wells						
1	Ravenswood				86.4	9.7	3.9
2	Kent				85.9	8.4	5.7
3	Kaylong	85.4	2.9	11.7	79.3	13.3	7.4
4	Point Pleasant				78.5	15.2	6.3
5	Lakin				77.8	11.5	10.7
6	Natrium	84.9	11.8	3.3	70.3	14.8	14.9
7	Kaylong	77.8	17.1	5.1	68.9	18.0	13.1
8	Glen Dale				60.9	29.3	9.8
9	Beech Bottom				55.4	33.8	10.8
10	McMechen	65.4	15.8	18.8	53.9	41.1	5.0
11	Wellsburg				52.4	34.3	13.3
12	McMechen				47.6	44.2	8.2
13	Kaylong	73.4	13.9	12.7	44.8	37.8	17.4
14	Kaylong	65.6	29.8	4.6	41.4	45.8	12.8
15	New Martinsville	68.3	13.9	17.8	39.3	46.8	13.9
16	Paden City	57.8	17.3	24.9	33.3	38.7	28.0
17	Follansbee				32.3	53.2	14.5
18	Parkersburg	62.6	18.6	18.8	32.0	52.4	15.6
19	Parkersburg				26.2	56.6	17.2
20	Chester				23.7	59.1	17.2
21	Moundsville	59.2	16.5	24.3	23.1	58.5	18.4
	Water From Ohio River						
A	Benwood	54.0	18.4	27.6	33.0	58.6	8.4
B	Cincinnati, O.	54.4	16.1	29.0	25.0	57.3	17.7
C	Sistersville				21.4	65.8	12.8
D	Kaylong				14.8	50.3	34.9
E	Cincinnati, O.	52.2	15.7	32.1	14.7	51.4	33.9
F	New Martinsville				8.0	83.0	9.0
G	Wheeling	56.7	20.0	23.3	4.8	80.0	15.2
H	Wheeling				1.4	85.3	13.3
I	Martins Ferry, O.	53.7	21.8	24.5	1.2	86.4	12.4
J	Wheeling	52.0	21.2	26.8	0.9	87.0	12.1
K	Weirton	43.5	17.9	38.6	0.9	85.4	13.7

(a) Calculated. (b) By turbidity. (c) Determined. (d) Includes 0.61 ppm. manganese. (e) Includes 1.3 ppm. manganese. (f) Includes 0.8 ppm. manganese.

River Valley are the total hardness, alkalinity (or bicarbonate) and sulfate. The pH, free carbon dioxide and iron are of little or no value for this purpose.

Analyses of water from the Ohio River and from water-bearing strata along the upper Ohio Valley are given in Table 1, in which the concentrations of the chemical elements or combina-

tions of elements which react as elements are expressed in parts per million.

In order to eliminate the effect of concentration and to indicate the chemical character of the waters, rather than the physical weight of dissolved substances, the values of the major ions given in these analyses were converted first to equivalents per million by multiplying the weight of each ion by a number equal to the valence of the ion divided by its atomic weight. As the sum of the equivalents of the anions (carbonate, bicarbonate, sulfate, chloride and nitrate) in a natural water is equal to the sum of the cations (calcium, magnesium, sodium and potassium), the analyses were adjusted somewhat to compensate for any lack of balance. The values of the ions then are converted to percentages of the total equivalents of the cations or anions (Table 2).

The detailed analyses showing both the major cations and anions are plotted on Fig. 1, according to the single-point method described by Langelier and Ludwig, to illustrate the general characteristics of the water (4). The percentage of non-carbonate anions (sulfate, chloride, fluoride and nitrate) and of the alkali cations (sodium and potassium) are scaled off from the lower left corner on the base and left side of the rectangle, respectively, and extended normal to these sides. The analysis then is represented by a single point located at the intersection of two vectors. In all these waters the percentage of non-carbonate anions is greater than that of the alkali cations so that only the lower half of the regular rectangle is necessary. The waters may be classified into subtypes according to the particular smaller triangle in which their plotted points occur.

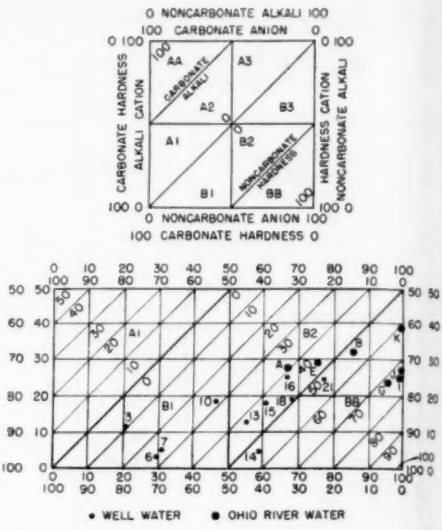

FIG. 1. Character of Ohio River Water and Water From Alluvial Water-Bearing Formations Along Ohio Valley, as Shown by Detailed Analyses.

The points falling in triangle B1 are characterized by a dominance of carbonate hardness, those in BB non-carbonate hardness, and those in B2 hardness, but having no dominant type. The percentages of the following properties and constituents of each water can be scaled readily from the position of the points on this diagram also:

Properties	*Constituents*
Carbonate hardness	Alkali cations
Non-carbonate hardness	Hardness cations
	Carbonate anions
Non-carbonate alkali	Non-carbonate anions

Water from the upper Ohio River, as shown on this diagram, is characterized by high percentages of non-carbonate anions and non-carbonate hardness. The well waters, however, range from those containing only small percentages of non-carbonate hardness to a few that approach the character of

the river water. It will be shown in the following discussion that these differences in the character of the well waters give an important indication of the quantity of river water reaching the wells.

For use in determining the source of the water recharging any particular well field, analyses showing only the major anions seem to be adequate. The greatest difference between the Ohio River water and normal ground water is in the concentration of sulfate and bicarbonate.* Therefore, when the percentage of bicarbonate as equivalents is plotted against the percentage of sulfate as equivalents for the analyses given in Table 1, the points representing the analyses separate into three groups, representing river water, normal ground water and mixtures of river water with normal ground water (Fig. 2).

Normal ground water along the upper Ohio Valley varies slightly in character locally, and the concentrations of the ions in the river water are even more variable. However, the approximate percentages of river water in each of the well waters indicated by the diagonal scale on Fig. 2 are believed to be sufficiently accurate for practical purposes.

The presence or lack of recharge by water from the Ohio River may be shown also by periodic determinations of the total hardness and alkalinity of the well water. However, this method does not permit satisfactory estimates of the amount of river water entering the aquifer in the vicinity of the well.

In general, appreciable fluctuation of any of these properties in excess of possible analytical errors indicates that river water is entering the aquifer. These conclusions may be confirmed by comparing the data with fluctuations in the stage of the Ohio River. Although the quality of the river water varies in accordance with the season and flow (Fig. 3), its hardness and alkalinity are below that for normal ground water at least during most of the year. The hardness and alkalinity of the water from formations that obtain a substantial portion of recharge from the river increase gradually during long periods of low river stage, generally during the summer and fall, and decrease abruptly during periods of flood or high river stage, such as occur typically in the early spring.

The data obtained from the unusually good records kept by the Parkersburg Water Department during the last fifteen years indicate these relationships for a well system that re-

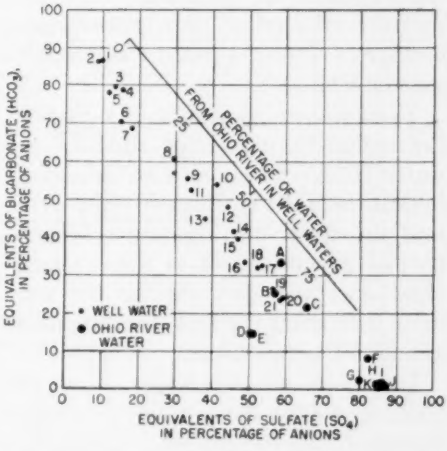
EQUIVALENTS OF BICARBONATE (HCO_3), IN PERCENTAGE OF ANIONS
EQUIVALENTS OF SULFATE (SO_4) IN PERCENTAGE OF ANIONS
FROM OHIO RIVER IN WELL WATERS
PERCENTAGE OF WATER
WELL WATER
OHIO RIVER WATER

FIG. 2. Source of Recharge to Alluvial Water-Bearing Formations, as Shown by Percentage of Sulfate and Bicarbonate in Ohio River Water and Water From Wells Along Ohio Valley—Diagonal Scale Indicates Probable Approximate Percentage of River Water.

* Bicarbonate in parts per million is equivalent to alkalinity in parts per million multiplied by 1.22.

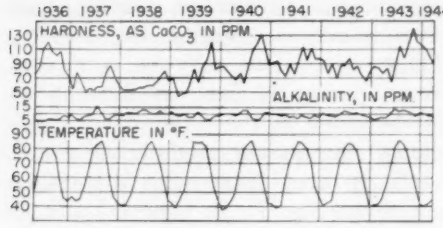

FIG. 3. Fluctuations in Average Monthly Alkalinity, Total Hardness and Temperature of Ohio River Water at Sistersville, W.Va.—Data From Sistersville Water Dept.

ceives important quantities of water from the river (Figs. 4 and 5). The abrupt decrease in the hardness and alkalinity of the well water during periods of high river stage, as in March, April and December (Fig. 5), indicate that large quantities of river water are entering the water-bearing strata at these times. The increase in hardness to a maximum in late fall and winter is attributed partly to a gradually increasing hardness in the river water and partly to the effect of a greater percentage of normal ground water reaching the well.

Temperature of Water.—A marked fluctuation in the temperature of the water from wells is also an important indication of the entrance of river water into the water-bearing strata because normal ground water in these formations does not vary during the year more than a few degrees from the mean annual air temperature.

Inasmuch as the water from the wells at Parkersburg ranges approximately from 46° to 66° during the year (Fig. 4) and its temperature fluctuates sharply at periods of high river stage (Fig. 5), it is evident that an appreciable part of the recharge is obtained from the river throughout the year.

Figure 6 illustrates the variations in the temperature of the water from the six wells at the West Virginia Ordnance Works, Point Pleasant. A detailed study of extended pumping tests and other data indicated that the percentage of river water is greatest at wells 2, 3, 5 and 6, moderate at well 4 and very small at well 1. The magnitude of the fluctuations in temperature, as shown in Fig. 6, is in accordance with these conclusions regarding the source of the water for each well.

Importance of Recharge by River Water

The source of the water replacing that withdrawn by wells from the water-bearing formations along the Ohio Valley is not merely a matter of academic interest; rather it is a factor of the greatest practical value. The infiltration of river water into the water-bearing strata is significant primarily because of its effect on the quality and the quantity of water that may be withdrawn over long periods of time without critically depleting the available supply.

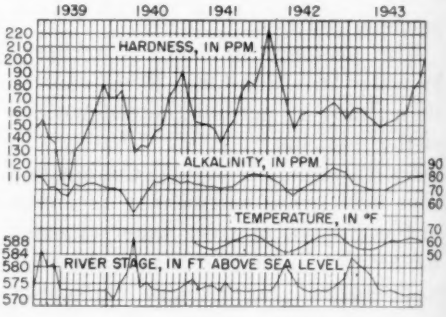

FIG. 4. Fluctuations in Average Monthly Content of Free Carbon Dioxide, and in Total Hardness, Alkalinity and Temperature of Parkersburg Well Water and in River Stage at Parkersburg, W.Va.

The objectionable tastes and odors and large numbers of pathogenic bacteria commonly present in the raw water taken from the Ohio River are removed or reduced to acceptable concentrations before the river water reaches the wells. The water should, of course, be tested periodically as prescribed by the state health department, and chlorination or other treatment should be applied if needed.

Regular determinations of the total number of bacteria and of the concentration of coliform bacteria made at Parkersburg and irregular tests at other water works where river water is recharging the aquifer show relatively low bacteria counts and very infrequent occurrence of coliform bacteria. A summary of typical data recorded by the Parkersburg Water Works is shown in Table 3 and 4.

Occasional high bacteria counts or positive coliform tests could result easily from minor errors in technic or contamination of the water after it reaches the well. When it is considered that no allowance is made in these tables for contamination of the water during floods when river water can enter some wells directly, maintenance work on wells or pumps, and temporary breaks in the raw-water main, it is evident that the bacterial quality of the water is entirely satisfactory. Moreover, there is no indication of any deterioration in the sanitary quality of the Parkersburg water in the fifteen-year period during which river water has been entering the water-bearing formation.

The composition of normal ground water at most places is relatively unchanged throughout the year so that

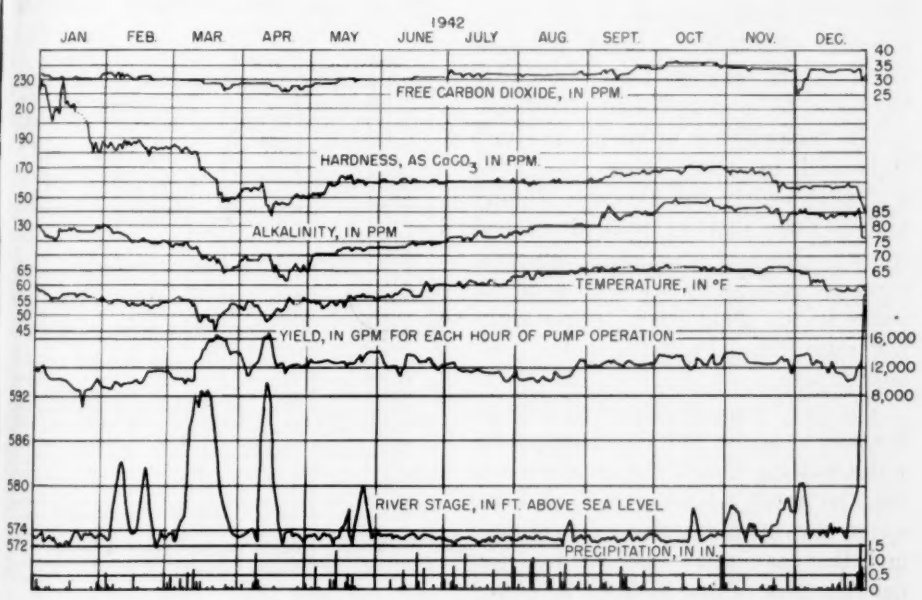

FIG. 5. 1942 Daily Fluctuations in Content of Free Carbon Dioxide, and in Total Hardness, Alkalinity and Temperature of Parkersburg Well Water—River Stage and Precipitation at Parkersburg and Yield of Wells for Each Hour of Pump Operation

TABLE 3

Frequency of Bacteria in Mixture of Normal Ground Water and River Water From Wells at Parkersburg

(Data summarized from 202 daily tests in 30 months during 1935–1938)

No. of Bacteria (Plate Counts After 24 hr. at 37° C.)	Frequency
0	34
1 to 5	132
6 to 25	32
26 to 100	2
More than 100	2

TABLE 4

M.P.N. Coliform Bacteria

(Indicated by 203 tests of Parkersburg well water in 30 months during 1935–1938)

No. of Positives in 5 Samples	No. of Individual Tests for Gas-Forming Bacteria	M.P.N. Coliform Organisms in 100-ml. Sample
0	182	less than 2.2
1	12	2.2
2	3	5.1
3	5	9.2
4	1	16.0
5	0	more than 16.0

treatment procedures may be standardized readily. The composition of water from aquifers that are recharged by river water, on the other hand, is quite variable, depending upon the rate and duration of pumpage, the stage of the Ohio River and the fluctuations in the quality of the river water. The mixing of river water with normal ground water in the aquifer tends to reduce the total hardness of the water pumped, although the most apparent effect is the change from carbonate hardness to non-carbonate hardness.

The temperature of water in strata recharged by water from the river fluctuates widely and averages slightly higher than that of normal ground water. However, maximum temperatures are sufficiently below those of the water in the Ohio River to make the water preferred by industry for cooling purposes.

The most important uses of data on the source of the water recharging the water-bearing strata are in determining the most advantageous sites for wells, the most suitable type of well and the maximum safe yield. Frequently it is desirable, also, to obtain such records to decide whether silting of the river bottom has decreased the amount of recharge from the river.

If an investigation indicates that little or no river water percolates into the water-bearing strata even when the water table is lowered by pumping below the level of the river, the capacity of the well field is limited to the quantity of water supplied by recharge from local precipitation on the surface. The water stored in the aquifer would permit a somewhat higher rate of pumpage at first, but this water would be

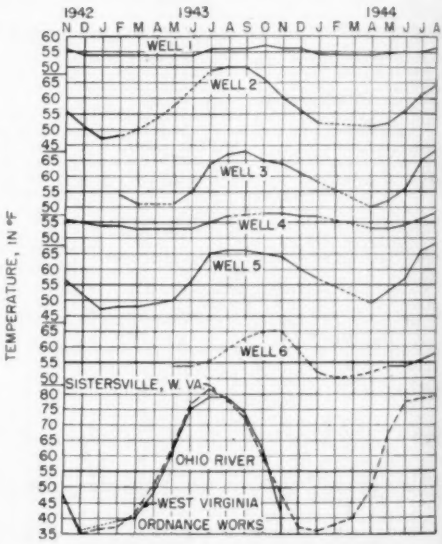

FIG. 6. Fluctuations in Average Monthly Temperature of Water Pumped From Each of Six Wells at West Virginia Ordnance Works, Point Pleasant, W.Va.

emoved rapidly. Additional supplies of water would have to be obtained rom wells a considerable distance way where they would not intercept echarge normally reaching the original vell. If it is necessary to construct wells under these conditions, they should be located in the thickest and most permeable section of the water-bearing formation without regard to the position of the river.

In areas where river water is moving into the aquifer or where it would enter if wells were pumped heavily, large quantities of water, in addition to that obtained from local precipitation, may be withdrawn. Therefore, he supply can be increased indefinitely y constructing additional wells at new ocations along the river. Where a onsiderable supply of water is required, construction of large diameter aissons equipped with several lateral screened collector pipes may be advantageous. A properly located well of this type along the Ohio River in West Virginia may yield from 2 to 4 mgd. under continuous operation.

The wells should be located adjacent to the river, where they will obtain a maximum amount of water from the river, together with the available normal ground water. If wells of the ordinary vertical type are used, they may be somewhat closer together than if they are of the collector type.

The yield of wells drawing water from aquifers partially recharged by river water will increase appreciably during high river stages, but the yield will not be affected as much by variations in local precipitation. Inasmuch as the viscosity of the water is proportional to the temperature and the rate at which water percolates into and through the water-bearing strata is influenced by the viscosity, the yield may vary considerably in accordance with temperature changes. Normally, the decline in yield due to the greater viscosity will be most perceptible in the latter part of the winter before the first high river stages.

The value of reliable data on the source of the water recharging the water-bearing strata may be illustrated by applying them to conditions at the Parkersburg Water Works.

At Parkersburg increasing consumption of water, together with a decrease in the yield of wells, has caused critical water supply problems during the past few years. If all the water was obtained from local precipitation without appreciable recharge from the river, it is apparent that new wells within the well field would not solve the problem. However, data shown on Figs. 2, 4 and 5 indicate that a major portion of the water is derived from the Ohio River. Thus, the construction of more wells would increase the available supply of water. As an emergency measure, several wells were constructed during the past year; some between the old wells about 100 to 150 ft. from the river and others only about 50 to 75 ft. from the bank. The substantially larger amounts of water obtained from those adjacent to the river illustrate the advantage of locating wells close to the river bank.

The Parkersburg water supply can be augmented further by constructing other wells near the river at locations somewhat beyond the present areas of heavy pumpage. A few properly constructed wells on Neal Island, if tests revealed equally good conditions of recharge from the river, should furnish sufficient water to replace most of the present supply obtained from numerous low-capacity wells and the infiltration bed in the river.

Summary

The alluvial water-bearing strata along the Ohio Valley furnish large supplies of water to numerous public water supply systems and industrial plants. Because the water obtained from wells is cooler than the water in the river during most of the year and because it lacks the objectionable tastes and odors commonly present in the river water, these water-bearing formations will continue to supply a large proportion of the water used for industrial and public supply in this part of the state.

The water replacing that withdrawn from the sand and gravel strata by means of wells is derived by the downward percolation of local precipitation and, locally, by infiltration of water from the Ohio River. The approximate amount of river water reaching any particular well or group of wells can be determined readily by obtaining the percentage of bicarbonate and sulfate, and comparing these with similar data on water from the Ohio River and from wells which obtain little or no recharge from the river. Significant fluctuations in the temperature, hardness and alkalinity of the water also indicate appreciable recharge from the river. More definite data on the quantity of river recharge can be obtained from properly conducted pumping tests and measurements of water levels in nearby observation wells.

The source of the water recharging the water-bearing formations is one of the most important factors to be considered in deciding upon well sites. If river water does not replace part of the water withdrawn from the wells, the yield is limited to the amount of water obtained from local precipitation, and the wells should be scattered widely. Where river water is entering the aquifer, the perennial yields of properly constructed wells may be substantially greater.

Acknowledgments

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Ground Water Problems in North Carolina

By M. J. Mundorff

Asst. Geologist, U.S. Geological Survey, Raleigh, N.C.

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GROUND water is one of the most valuable natural resources in North Carolina. Almost all of the rural population uses water from wells or springs and about 400,000 people are supplied with ground water by 175 municipalities and 22 military establishments. Approximately 2,500,000 people, 70 per cent of the total population of the state, depend upon ground water for their water supply.

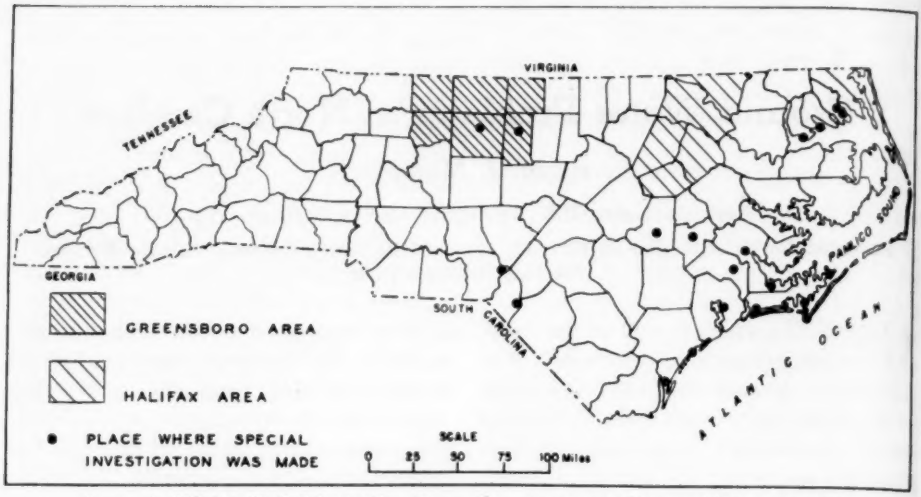
Of the several million dollars spent each year in obtaining this water, a considerable part is spent in digging, boring and drilling new wells. Unfortunately, part of this money is used unnecessarily because of inadequate knowledge of ground water conditions.

Investigations Being Made

Realizing the need for study of the state's ground water problems, the State Department of Conservation and Development entered into an agreement with the United States Geological Survey to conduct a co-operative investigation of the ground water resources of North Carolina. In July 1941, the author was assigned to this project, which is continuing at the present time. The program is under the direction of Dr. J. L. Stuckey, State Geologist of North Carolina; and Dr. O. E. Meinzer, Geologist in charge of the Division of Ground Water, U.S.G.S.

The purpose of the project is to determine the quantity and quality of water available from the underlying water-bearing formations in the various parts of the state; to develop criteria for choosing favorable locations for drilling and digging wells; to determine the chances of increasing the yield with increasing the depth of the well; to ascertain the areas capable of supplying large quantities of water for industrial development; and to determine the quantity and quality of water available from each aquifer in such areas.

It was considered advisable to use the counties as the basic units for field work and to publish reports covering the investigations of areas consisting of one or more counties. The first area in which ground water studies were undertaken is the Halifax area, consisting of Northampton, Halifax, Nash, Edgecombe and Wilson counties. The report of this area has been completed and is being published as Bulletin 45 of the State Department of Conservation and Development. The second is the Greensboro area, consisting of Alamance, Caswell, Guilford, Rockingham, Forsyth and Stokes counties. The field work in this area has been completed and the report is being prepared. These two areas were chosen because of the need for information on their ground water resources and also



Areas in Which Full Work Has Been Completed and Places Where Special Investigations Were Made for Military Establishments or in Defense Areas

because they are representative of a large part of the state.

Because of the many military establishments built in the Coastal Plain of North Carolina, all of which use ground water, much time has been devoted to that area. A large amount of valuable information has been obtained, including well logs based on examination of drill samples and data on the quantity and quality of water available from the various aquifers.

The accompanying map shows the areas in which investigations of ground water have been made.

Ground Water Problems in the Piedmont and Mountain Sections

In this area, especially in the central Piedmont, are the most highly industrialized sections of the state, and many million gallons of water are pumped daily.

The ground water problem which has received the most attention in this region has been that of choosing the most favorable location for drilling wells in order to obtain the largest possible yield. Although criteria for selecting well sites have not yet been fully determined or thoroughly tested, knowledge of certain geologic factors is very helpful. Factors to be considered include texture of the rocks, jointing, bedding planes, schistosity and cleavage (if present); presence or absence of dikes and veins; topographic location; and depth of the weathered mantle. Most of these factors are inter-related and rarely will all of them be equally important in any one area.

Texture. Generally the coarser-textured rocks are better aquifers than the finer-textured ones.

Jointing and other fracturing. Except for the sands and silts found along the flood plains of some streams, the rocks of the Piedmont and Mountain sections are consolidated and their ground water occurs chiefly in joints and similar fractures. Therefore, wells drilled at places where the rock is more closely jointed, sheared or fractured will usually yield more water than wells drilled into massive parts of the rock formation.

Bedding planes. Rocks of sedimentary origin have bedding planes along which water may move. Even though these rocks may have been greatly altered by metamorphism, the bedding planes are usually preserved to some extent. In some places, folding and shearing has increased the separation along these bedding planes so that they generally are important avenues of ground water movement in the rocks of sedimentary origin found in the Piedmont. Places at which the bedding planes are closely spaced generally are more favorable for drilling wells than places where they are widely spaced. Places where the dip of the bedding is low also are favorable, as more bedding planes will be intersected in a well of given depth.

Schistosity and cleavage. These are planes of separation developed by heat and pressure at great depths which the rocks have undergone subsequent to their origination. They have a significance similar to that of the bedding planes. The more highly schistose rocks and those with greatest cleavage generally furnish the larger yields.

Dikes. Dikes are rock bodies emplaced while the rock is still molten. Usually they are in the nature of walls of lava extending vertically through the formation into which the lava was intruded. Very often they have baked and fractured the strata through which they were injected, and wells drilled into the strata adjacent to the dikes have frequently proven to be better than average water producers.

Veins. The presence of quartz veins is generally considered as a favorable indication in choosing a well site. Being a hard brittle mineral, quartz fractures and breaks during earth movements. As there has been considerable movement subsequent to the emplacement of the quartz veins found in the Piedmont, most of them are fractured to some extent. Not all quartz veins serve as avenues for the movement of ground water, but some of the best wells in the Piedmont have been so located that they intersect quartz veins at depths of from 100 to 300 ft.

Topographic location. The topographic location appears to be most important in rocks of igneous origin. It is thought to be important for two reasons. First, other factors being equal, a hill is caused by the presence of more resistant rock. The rock may be more resistant because it is harder or because it is relatively free from joints and other fractures which allow the rock to be eroded. According to this reasoning, the valleys are cut into the rock where fracturing has been more intense, and therefore wells drilled in the valleys will encounter more greatly fractured rocks. Second, the movement of ground water is generally toward the valleys where it discharges into streams and away from the hills; therefore, the natural movement of the ground water is away from the wells drilled on hills and toward the wells drilled in valleys. Topographic location is probably less important in bedded rocks, except possibly in those in which the bedding is vertical.

Thickness of weathered mantle. Because the extent of chemical weathering of a rock depends largely upon the ease of access of water to the rock, a thick mantle of weathered material overlying the bedrock from which it was derived is an indication that the rock is jointed and fractured or has interstices of some other type through which water can move.

Other ground water problems have received less attention but are also important and need careful study. The

depth at which an unsuccessful hole should be abandoned has yet to be established. This depth undoubtedly varies greatly with the type of rock into which the well is being drilled, as well as depending upon other geologic factors such as were mentioned in connection with selection of a well site. Economic factors also may have a bearing on this problem. From the data collected to date, it appears that the majority of successful wells obtain a large part of their water from the upper few hundred feet.

The average yields of wells in the several kinds of rock found in the Piedmont vary considerably. Information regarding the yield that can be expected from a well in rock of a given type is important in estimating the ground water possibilities of a particular location.

The effect that the removal of large quantities of water has upon the water table and upon the yield of nearby wells is also important. Connected with this problem is that of the optimum spacing of wells in a limited area.

The principal problem concerning quality of water in the Piedmont and Mountain sections of the state is that of hardness. The hardness of the water is closely related to the mineralogical and chemical nature of the rock. Careful geologic study probably will permit a fairly accurate prediction of the hardness of water which can be obtained at any place, after the relation between the various types of rock and the hardness of the water have been established. From the data now available, it appears that some of the hardest water in this area is obtained from the metamorphosed tuffs and breccias of the Carolina slate belt. Some granites also yield rather hard water, but others yield soft water. Apparently, those granites approaching grano-diorite, thus having more calcium and magnesium, yield harder water than the true granites. Most of the schists and many of the gneisses yield soft water, though some, probably those with a higher percentage of minerals containing calcium and magnesium, yield harder water.

Iron content and corrosiveness are closely related problems. Water from some wells contains objectionable amounts of iron that have been dissolved from the soil and from the rocks, but in other wells the iron is dissolved from the well casing and pump pipes by the corrosive action of water containing carbon dioxide.

Problems of the Coastal Plain

Enormous quantities of ground water are available in the Coastal Plain of North Carolina, but only a small percentage of the amount available is being used. It is probable that increasing use will be made of this important natural resource in the future.

At the present time the ground water problems of the Coastal Plain are chiefly those dealing with the quality of water and those problems of quantity relating to the yield of individual wells. At a few places, mostly at military bases, the quantity of water that can be obtained from a restricted area has also been an important problem. As more ground water is used in the Coastal Plain because of increased agricultural and industrial development, the quantitative problems dealing with the perennial yield of an aquifer, mutual interference and spacing of wells and similar problems will become more important.

Quantity of Water in the Coastal Plain

The principal aquifers in the Coastal Plain are strata of sand and gravel and

beds of semi-consolidated shell rock which occur in the various formations.

As these water-bearing strata are rarely uniform over any considerable area, the primary problem in the Coastal Plain is that of obtaining sufficient data to disclose the depth, thickness and nature of these strata. Correlation of these data, especially by means of accurate well logs, will help in determining the extent and continuity of the aquifers.

Measurement of water levels, in both artesian and non-artesian strata, and reference of these measurements to a common datum (preferably mean sea-level) permit water table and piezometric maps to be drawn. Not only is this of great value in determining the recharge areas and their extent, and in correlating the aquifers, but also it enables accurate predictions to be made regarding the water level before wells are drilled, thus assisting in choosing the proper type of well and pumping installation.

Overdevelopment and possible depletion of ground water supplies can be prevented by keeping an adequate record of the fluctuations of the water table, and using these records to govern the rate of pumpage and the spacing of the wells.

The problem of safe perennial yield of an aquifer requires the accumulation of the data mentioned above, and, in addition, data concerning recharge areas and extent of recharge to the aquifer, and the permeability and specific yield of the aquifer. All of this information is required to determine the safe perennial yield from the aquifer at any one place or from the entire aquifer. These data are also necessary to determine the mutual interference of adjacent wells and the optimum spacing of these wells.

Quality of Water in the Coastal Plain

Many different types of water are obtained from the aquifers of the Coastal Plain. At many places there is a choice between two or more types of water contained in the aquifers encountered at different depths. The primary problem is to determine the character of the water in the several aquifers at various places. This is complicated by the fact that the water in an aquifer often has a considerable lateral variation. Usually these changes can be correlated with changes in the geology.

Some formations, such as the Tuscaloosa and Black Creek formations of Upper Cretaceous age, yield soft water low in dissolved solids at almost every place in which they have been encountered in the southern half of the Coastal Plain. North of the Neuse River the water from the upper part of the Cretaceous beds is usually moderately hard but the water at greater depths has been softened by base exchange. Delineation of the areas in which soft water can be obtained and determination of the depths to the aquifers yielding it are important problems.

At many places in the eastern part of the Coastal Plain brackish water is encountered at a depth of 100 to 500 ft. below the surface. At such places it is necessary to locate satisfactory aquifers at shallower depths. It is also important to guard against possible contamination of the shallower fresh water aquifers by the deeper brackish water. This appears to be occurring at one place in North Carolina, and further investigations are being conducted to determine the source of the contamination and to effect a remedy.

Contamination of fresh water aquifers can also result from the entrance

of brackish water from nearby surface bodies of salty water. Such contamination occurred at New Bern where the wells were located too near the Neuse River, and it was necessary to drill new wells at a greater distance from the river. Similar contamination appears to be occurring at Wilmington, where many industrial wells located near the Cape Fear River have become brackish.

Objectionable amounts of iron in the water adversely affect the use of many wells in North Carolina. The occurrence of iron in the ground water appears to be very erratic and requires more study. Data obtained to date indicate a decrease in iron content with increasing depth, as is shown below:

Iron Content in Wells Between Specified Depths

Range in depth, *ft.*	0–50	51–100	101–150	151–200	above 200
Iron, *ppm.*	2.2	1.14	1.23	0.75	0.51
Number of analyses	17	23	17	16	37

Corrosiveness of ground water, due principally to the presence of carbon dioxide, not only causes deterioration of pumps, pipes, etc., but is also objectionable because the dissolved iron stains fixtures, utensils and laundry. The problems of iron and corrosiveness are closely related and both are serious problems for domestic and small municipal and industrial users.

Fluoride in excess of about 1 ppm. may cause the dental defect known as mottled enamel, if the water is used for drinking and cooking during the formation of the teeth. There apparently is only one important area in the Coastal Plain in which ground water with an excessive fluoride content is found, although a few scattered wells at other places have a fluoride content somewhat larger than 1 ppm. The main area of relatively high fluoride appears to extend from Pactolus, in eastern Pitt County, northeastward through Windsor and Gatesville into Virginia. The high fluoride water is obtained from wells 200 to 500 ft. deep, ending in sand which may belong to the deposits of lower Eocene age.

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Ground Water Investigations in Pennsylvania

By George H. Ashley and Jack B. Graham

State Geologist, Topographic and Geologic Survey, State Dept. of Internal Affairs, Harrisburg, Pa.; and Asst. Geologist, Div. of Ground Water, Water Resources Branch, U.S.G.S., Washington, D.C.

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IT has been the fashion recently to speak of countries as "haves" or "have nots." Commonly the expressions refer to possession or lack of enough arable land or of the minerals that play so large a part in our modern, material civilization. The time is approaching, if it is not already here, when "have" or "have not" will also apply to adequate water supplies. It is hoped that in the future, engineers whose duty it is to locate large military and manufacturing establishments requiring much water will realize that the water supply is of prime importance. Such mistakes as occurred at the beginning of the present war, when water supplies sometimes were the last thing to be given consideration, should not be repeated. In at least one or two instances construction was stopped and the whole project moved to another state when it became evident that enough water could not be obtained at anything like a reasonable cost.

In the old days when people could be happy, if not healthy, if they had a well and a moss-covered bucket, water was no problem. When plumbing, bathtubs and modern sanitary facilities were introduced, to find an ample water supply often became a real problem, and in many instances could be solved only by the use of storage tanks or reservoirs. Then came the private swimming pool and air-conditioning, and today, with the prodigious quantities of water used in connection with central power production and many industries, the problem is serious.

With sufficient diplomacy, technical skill and good will, it is possible to supply all the people of the world with all the food and minerals necessary for all peacetime needs. But because of the bulk and weight of water, in many instances it is more economical to move the people or the plant to the water.

Geology of Pennsylvania

While it is true that surface water yields differ greatly between areas, the difference in ground water yields is often much greater. Where the underlying rocks are flat-lying, these differences may be between townships or counties or even larger areas. But where, as in Pennsylvania, most of the rocks are highly folded, the differences may be between farm and farm and even between lines of strata only a few feet apart. Certain rocks, such as granite, limestone or quartzite, are so close grained that they will yield no water at all unless a well penetrates fractures, bedding planes or solution channels. Because of faulting, folding, overlaps, igneous intrusions and other disturbances, a detailed geologic map of southeastern Pennsylvania presents a complex of many kinds of rocks all jumbled together. Water supply con-

ditions, therefore, may vary from farm to farm, from one side of town to another or even from one backyard to the next.

In other parts of the state the rocks are more orderly and throughout the central counties are exposed in long parallel and zigzag bands, the result of folding. But, again, many of the rock formations up to several thousand feet thick are anything but uniform in character, especially in regard to their water-bearing qualities. A formation may consist of shale and sandstone, the sandstone, which carries the water, being in lenses of varying extent and thickness; or regular layers of sandstone with interbedded shale may dip in such a way that a well at one point will strike an entirely different section of beds from one drilled only a few hundred feet away. Beds of rock of uniform character are seldom more than a few hundred feet thick in Pennsylvania; and if such beds are highly inclined the zone underlain by such uniform rock presenting uniform ground water conditions may be only a few hundred to a few thousand feet wide, with entirely different conditions on both sides. In the western part of the state, where the rocks lie more nearly level, most of the porous sandstones carry salt water to within a few hundred feet of the surface, depending on the topography and other factors.

As a result an accurate knowledge of the geology of Pennsylvania is required if one is to predict what is likely to be found at any point or in any particular area.

Ground Water Investigations

Ground water investigations began in Pennsylvania in 1925 under a cooperative agreement between the state and the federal government, the Pennsylvania Geological Survey acting for the state and the Ground Water Division of the Water Resources Branch of the U.S. Geological Survey for the federal government. The agreement continued to 1935, by which time all parts of the state had been covered by a reconnaissance survey, resulting in seven reports ranging from 200 to 400 pages each.*

Each report is accompanied by a geological map of its area on a scale of 6 in. to the mile. Where conditions vary from farm to farm, obviously such reports and maps, although of great value, cannot be adequate for determining large supplies for industrial or chemical plants. Where the folding is broad and the dips not too steep there may be considerable areas in which ground water conditions are fairly constant. In such areas these preliminary reports serve fairly well, because in such broad areas enough data can be gotten, even in a reconnaissance survey, to give a reasonably accurate picture. In areas of similar extent, however, where many different rocks come to the surface and local folding disturbs the regularity of the strata, only one or two wells may be recorded in a given rock formation and their yield

* Bulletin W 1, Ground Water in Southwestern Pennsylvania, by A. M. Piper, 1933.
Bulletin W 2, Ground Water in Southeastern Pennsylvania, by G. M. Hall, 1934.
Bulletin W 3, Ground Water in Northwestern Pennsylvania, by R. M. Leggette, 1936.
Bulletin W 4, Ground Water in Northeastern Pennsylvania, by S. W. Lohman, 1937.
Bulletin W 5, Ground Water in South-central Pennsylvania, by S. W. Lohman, 1938.
Bulletin W 6, Ground Water in North-central Pennsylvania, by S. W. Lohman, 1939.
Bulletin W 7, Ground-Water Resources of Pennsylvania, by S. W. Lohman, 1941.

may or may not be characteristic of the formation.

In 1930 a start was made in gaging water wells to determine the depletion of ground water supplies by drought and replenishment in seasons of abundant rainfall or melting snow. At the present time 25 representative wells are being gaged. These wells are far enough from areas of large demand to make them representative of normal conditions. The data on these wells are published annually in the reports of the U.S.G.S. on water levels and artesian pressures in observation wells in the United States.

One of the most valuable uses of these records is in connection with the forecasting of stream flow, as the fair-weather flow of streams is derived from subterranean sources. The Pennsylvania Power and Light Co. is already using these data in forecasting conditions in the Susquehanna River drainage and they have been invaluable in securing maximum production of power from the hydro-electric plants.

In 1943 money was made available for beginning a detailed study of the state's ground water resources. The junior author was assigned to the Philadelphia area to begin such a study. So many acute problems of large magnitude turned up at once that he has been kept busy aiding in their solution rather than in the broader study planned in the beginning. In solving these problems, however, a large amount of data has been gathered that will be valuable in the broader study. Among the special problems needing immediate solution was a more adequate ground water supply for South Philadelphia, and, particularly, for the Philadelphia Navy Yard, where there has been a large increase in the use of water because of the expansion of operations occasioned by the war. Some attention has also been devoted to the needs of other municipalities where water supplies are inadequate to meet the requirements of increased population and industrial growth. Some of these problems have taken the junior author as far west as Somerset County.

Future of Ground Water Resources

The increase in the draft on the ground water reservoirs in Pennsylvania in recent years has been chiefly for water supply for growing communities, increased industrial operations, air-conditioning and cooling purposes. This use of ground water has been due, in part, to the fact that ground water supplies, where available in sufficient quantity to meet the prospective need, can be developed much more quickly and, in general, more economically than surface supplies, which would require treatment and the construction of impounding reservoirs. Furthermore, less strategic and scarce materials are involved in such developments. However, for many industrial and manufacturing purposes, and particularly those involving cooling, ground water is especially advantageous because of its uniform quality throughout the year and because of its lower temperature. For municipal and domestic use it has the further advantage of high sanitary quality so that a minimum of treatment is required.

It is evident that water obtained from wells is of great value and it will increase in value with the growth and development of the state, the expansion of its industry and the more complete utilization of available water supplies. This demand of industry for water of good quality and of low temperature required for cooling purposes is going to become much more per-

sistent. An adequate water supply is a most critical factor in the selection of a site for an industrial plant. It is not practicable for an industrial concern to make detailed investigations to discover possible new sources of water supply adequate for its needs. As is frequently the case, a site is chosen because information is available to indicate that a supply can be obtained at a reasonable cost. The state is, therefore, confronted with a real opportunity for industrial expansion if it is able to offer reliable information on its water supplies. The situation is illustrated by the experience of Memphis, Tenn., which uses ground water for the municipal supply and all private supplies. When the U.S.G.S. made its investigation of the ground water conditions of the Memphis area in 1928, about 40 mgd. were pumped from wells. In 1944 the draft was in excess of 100 mgd. Admittedly, a normal growth of population would doubtless have been experienced in this region in the past 15 years, but nevertheless, the fact cannot be overlooked that an important factor in the great industrial growth of this community was the availability, in a comprehensible water supply paper, of reliable information indicating that a large supply of ground water of good quality could be developed economically.

Though general information on the ground water conditions of the state has been compiled, specific data are not available as to the quantity of ground water that is now being used or the location of areas in which substantial quantities of ground water may be developed and utilized by new industries or the expansion of existing industrial plants. Under the pressure of war necessity, many new ground water supplies have been developed in localities that heretofore have received scant consideration as sites for large industries requiring substantial quantities of water of good quality and of low temperature. At Geneva, in Crawford County, a supply of more than 10 mgd. was developed for the Keystone Ordnance Works. There is no doubt that many similar areas exist in the state which would likewise furnish large supplies of water to properly constructed wells. Such areas must, however, be defined by systematic ground water investigation supplemented by drilling and pumping tests to determine the quantity of ground water that is perennially available.

It is obvious from what has been said that only a beginning has been made in a thorough up-to-date study of the state's ground water resources. In submitting a budget for the coming biennium, a four-fold increase of money to be available for an expansion of the work in this line has been requested. The number of observation wells should be multiplied, a comprehensive inventory of the present use and need for ground water within the state should be made and intensive investigations of ground water conditions such as are being made in Philadelphia should be started in several large industrial areas in the state. Also the Pennsylvania Geological Survey should be in a position to answer calls from municipalities that find it necessary to increase their water supplies. Such calls often make necessary a considerable local study to determine the best sources of additional water. The program should, if possible, foresee where there is likely to be expansion of industries needing large supplies of water so that the information will be available as soon as it is wanted.

The Potentials of Ground Water Supplies of the Southwest

By Robert H. Dott

Director, Oklahoma Geological Survey, Norman, Okla.

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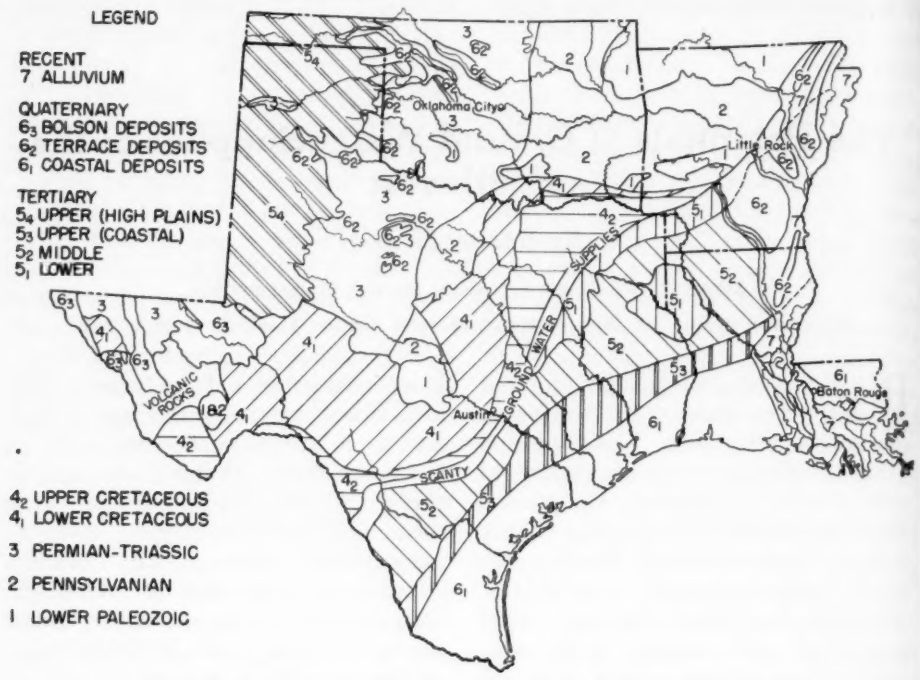
ROCKS of all geologic ages crop out in the four states in the Southwest (Arkansas, Oklahoma, Louisiana and Texas), offering a great variety of ground water conditions. The ground water potentialities of the region may be best summarized by grouping the more important aquifers geologically, discussing them chronologically, oldest to youngest, and pointing out the areas in which each group occurs. The accompanying map shows the areas underlain by each group. In each group of aquifers there is or could be a source of water supply.

1. *Lower Paleozoic* (1 on map) includes all rocks from Cambrian to Mississippian systems, inclusive. These rocks occur in five areas, in four of which they furnish important supplies of water: (a) Ozarks area of northwestern Arkansas and northeastern Oklahoma; relatively abundant water from limestones and sandstones, through springs and wells. The rocks dip to the south and southwest from the central Ozark area in Missouri. (b) The Ouachita Mountains of southwestern Arkansas and southeastern Oklahoma; slates and "tight" sandstones offer little promise for more than farm supplies. (c) Arbuckle Mountains, south-central Oklahoma; relatively abundant water from limestones, dolomites and sandstones. The area is well watered with many springs and there are some flowing wells on the north flank. Water from many of these wells is mineralized, but some areas offer promise of good water in considerable volume. (d) Wichita Mountains, southwestern Oklahoma; water from limestone and dolomite through flowing wells at the southeast end of the uplift, in the city of Lawton. The water is somewhat mineralized and has high fluoride content. Unlike most waters from limestone, this contains mainly sodium rather than calcium bicarbonate. (e) Central Mineral Region, south-central Texas; Sandstone and limestone, on the northwest flank of the uplift, produce flowing wells in the valley of San Saba River, southeast McCulloch County.

2. *Pennsylvanian System* (2 on map). Rocks of Pennsylvanian age, consisting of shale, sandstone and limestone, crop out in western Arkansas, eastern Oklahoma and north-central Texas. Only in east-central Oklahoma, where the Nelagoney-Vamoosa formation supplies important amounts of water, and possibly in parts of Texas, are the sandstones sufficiently thick and permeable to furnish other than local or farm supplies. These beds dip generally westward.



Map Showing Underlying Geological Strata of the Southwest

3. *Permian and Triassic* (3 on map). Red shale, sandstone, gypsum and salt beds of Permian age underlie western Oklahoma and a part of northwest Texas, dipping generally westward, except in the trough-like Anadarko basin in west-central Oklahoma. In Oklahoma three sandstone aquifers now are or could be developed as important sources of supply. Probably a few local aquifers with usable water occur in the Permian of Texas; but otherwise, thick permeable aquifers are lacking and most of the waters are too highly mineralized to be used.

The Triassic (Dockum group) crops out in a small area in the Oklahoma Panhandle and along the east margin of the Staked Plain in Texas. In the latter area, the Santa Rosa sandstone of the Dockum is of considerable local importance.

4. *Cretaceous.* Rocks of Lower and Upper Cretaceous age crop out in, and furnish water to, a broad S-shaped belt extending from southwestern Arkansas, past the central mineral region, into Trans-Pecos, Tex. The rocks dip generally southeastward. Cretaceous aquifers consist of thick, permeable limestones and sandstones and are of first importance in the amount of water available to the cities, towns, farms and ranches of Texas. The lower Cretaceous (4_1 on map) consists of the Trinity, Fredericksburg and Washita groups. The Trinity sand, with some gravel, furnishes water to small towns in a belt near Red River, east from Highway 77, south-central Oklahoma,

to the vicinity of Arkadelphia, Ark. Probably additional supplies can be developed.

Sands and gravels of the Trinity furnish large quantities of water to the area in Texas north of the central mineral region and west of the Balcones fault zone. Limestones of the Fredericksburg and Washita groups are important sources of water in the Edwards Plateau, west of the central mineral region, extending westward into Trans-Pecos, Tex. Many Texas cities are supplied in whole or in part from lower Cretaceous rocks.

The principal aquifers in the upper Cretaceous (4_2 on map) are the Woodbine sand in northeast Texas and the Woodbine, Bingen and Nacotoch sands in southwestern Arkansas, and they are of great importance in those areas.

The Woodbine sand underlies an L-shaped belt extending north from Hillsboro to Red River, thence east into Arkansas, through the southeast corner of Oklahoma. Roughly, the area in which good water can be obtained from the Woodbine is that part of Texas known as the Eastern Cross Timbers and the Black Land Belt (Black Prairie). Water in the Woodbine to the east and southeast is too brackish for use. Upper Cretaceous formations above the Woodbine contain some sands across the entire state from Red River to the Rio Grande, but are less important than the Woodbine.

Between the east limits of good water in the Upper Cretaceous area and the area underlain by the next younger water-bearing formation, there appears to be in Texas a narrow belt in which ground water of good quality cannot be had.

5. *Tertiary* rocks, mostly unconsolidated sands and clays, crop out in a wide belt extending from the Rio Grande northeastward across southeast Texas, northern Louisiana and southern Arkansas, parallel to the coast of the Gulf of Mexico and dipping toward it. There are six principal aquifers in the Tertiary, one in the High Plains and five in the Gulf Coast area, whose combined yields are of first importance in southeast Texas, much of Louisiana and part of southern Arkansas. Owing to the relatively higher rainfall in the southeastern part of this region, these formations receive and contain large volumes of water. Perhaps for this reason, water of good quality generally is found farther downdip, at greater distances from the outcrops and at greater depths than is the case with aquifers described heretofore. Several conditions combine to give an overlapping of areas of usable water from almost any two Gulf Coast Tertiary aquifers, resulting in the broad band shown on the map and permitting withdrawals from more than one water-bearing formation in certain areas. The surface of the land slopes toward the Gulf so that in most or all instances the mouths of the wells are lower than the outcrop or intake area. Hence, flowing wells are common.

The principal aquifers are as follows: The Wilcox formation (5_1 on map), which crops out in southeastern Arkansas, immediately adjacent to the Paleozoic rocks of the Ozarks and Ouachita Mountains, and trends southwestward across southwestern Arkansas and northeastern Texas, to the Brazos River in Milam County, where the formation becomes too impermeable to be a satisfactory aquifer. The Wilcox also is exposed on the Sabine uplift in eastern Texas and western

Louisiana, south and west of Shreveport.

The Wilcox is overlain by the Claiborne group (5_2 on map) containing three sands of good water-bearing properties: Carrizo, Queen City and Cook Mountain. The area served by these sands lies a little southeast of that of the Wilcox and extends from the vicinity of Eagle Pass and Laredo, on the Rio Grande northeastward, passing north and south of the Sabine uplift, and across the north half of Louisiana into southeastern Arkansas.

Above the Claiborne lie two sand formations of slightly different age called the Catahoula and Oakville (5_3 on map). They are considered as a unit in this discussion, and the belt which they underlie extends from the Rio Grande in Zapata County northeastward past Houston, Tex., and Alexandria, La.

Referring to the map, attention is called to the fact that the outcrops of Wilcox, Claiborne and Catahoula are not shown east of the Ouachita River. They are known to extend across the Mississippi River into the states of Tennessee and Mississippi, but in Louisiana and Arkansas are covered by younger terrace and alluvial deposits of the Mississippi River Valley. Some of them, at least, yield water in that area, as elsewhere.

The water-bearing formations described thus far contain, for the most part, water under artesian conditions. Those yet to be considered, with one notable exception, contain water under water table conditions.

The youngest Tertiary rocks known to have good water-bearing properties belong to the Ogallala formation, underlying the High Plains (5_4 on map). The Ogallala consists of sands and gravels and contains a large amount of calcium carbonate, making the water hard. The formation ranges from 100 to several hundred feet thick, on the average. Although it is only partly saturated, owing to the low rainfall of the area, it is highly permeable and gives up large yields to wells. The Ogallala underlies most of the Oklahoma and Texas Panhandles and the three west tiers of counties in west Texas, south of the Panhandle to the latitude of the south line of New Mexico. The water is under water table conditions.

6. *Quaternary.* Excepting one bedded formation on the coast, the Quaternary or Recent aquifers consist of surficial deposits of unconsolidated sands and gravels, alluvium, dunes and terrace deposits, and may be found in all parts of the region.

Adjacent to the coast, and extending 60 to 80 mi. inland, is an area underlain by Lissie formation and the succeeding Beaumont clay (6_1 on map). The Lissie consists of sand and gravel and furnishes very important supplies of water to cities in that belt. It is under artesian pressure, and many wells flow. This formation extends from the Rio Grande to, and probably beyond, the Mississippi River, although in the lower delta area the Lissie probably is covered by alluvium.

Terrace deposits (6_2 on map) occur as scattered patches of sand and gravel of the High Plains in western Texas and western Oklahoma, and along some of the major rivers in the same states; and along the west margin of the Mississippi Valley. They are remnants of former valley floors of the rivers when they flowed at higher levels. They have been dissected following the cutting down of the river valleys, but many of these terrace remnants are of considerable size, and, if

they consist of permeable material, make excellent local sources of water. Several cities in Oklahoma draw their supplies from such deposits; and they are indeed a boon, for the water is of good quality, and in many instances no other source is available.

Another type of surficial deposit that is important as a source of water supply is the valley-fill found in valleys in the arid region of Trans-Pecos, Tex. These are known as bolson deposits (6_a on map) and occur in intermontane valleys, attaining thicknesses of several hundred to as much as 1,000 ft. or more.

Last on the list is the alluvium of streams (7 on map), the material brought down to fill the present valleys. Only alluvium in the Mississippi River Valley is shown, although all the larger rivers of the region have broad, alluvium-filled valleys in parts of their courses, from which important supplies of water are obtained locally. The character of the material ranges from fine silt to coarse sand and even gravel, and its permeability and water-bearing property depend upon the character. In parts of Oklahoma and Texas, river alluvium is sufficiently coarse and permeable to furnish good yields to wells; but in Arkansas and Louisiana the material is too fine and is, therefore, a poor source of water, so that most wells in the larger river valleys go into the underlying Lissie or some of the Tertiary-formation.

Summary

Ground water is a very valuable asset. It supplies good water, conveniently, in many areas where no other sources are available, and generally at much less cost than surface supplies. Ground water is not inexhaustible, and unless developed and used wisely, much trouble can result. Overdevelopment should be avoided; wells should not be spaced too closely, and should not be pumped beyond safe limits. Ground water exploration and development are matters of application of geology and engineering, and headaches may be avoided by applying them properly before the trouble comes.

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Surface Water Resources of the Southwest

By Trigg Twichell

Hydr. Engr., U.S. Geological Survey, Austin, Tex.

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TODAY, as never before, people living in the Southwest (Arkansas, Louisiana, Oklahoma and Texas) realize the importance of conserving and controlling the quantity and preserving the quality of the water in the streams of the region. In recent years they have suffered severe property losses from floods; they have suffered crop losses from prolonged droughts that alternated with excessive rainfall seasons; and they have witnessed the phenomenal expansion of industry and the production of critical war materials which have made unpredictable demands upon the water resources. Stream pollution in the large urban and industrial areas is increasing at such a rate that it has become a serious menace to water supplies and a source of danger to public health.

Although the availability of water varies greatly, nature has provided that the existing supply in any given area will be replenished through a hydrologic cycle. The streams form a part of the distribution system of the cycle in that they carry the surface runoff back to the sea where it evaporates and eventually returns to the land in the form of rain. Through this endless and irregular cycle, nature provides water for man's use. The progress and probably the ultimate development of the region is highly dependent upon the systematic manner in which water resources are controlled, utilized and protected from pollution by man.

Man's effort to provide himself with water and to utilize the rivers for his beneficial use extend back to the time of his creation. One of the earliest metropolitan water supply systems was that of Rome. In 97 A.D., Rome and its metropolitan area was supplied with a daily maximum of 84 mil.gal. of water * through nine aqueducts having a total length of 250 mi. The daily per capita requirement at that time was about 38 gal. About 1845 years later, the Metropolitan Water District of Southern California, which serves about 3,000,000 people, constructed an aqueduct to bring 1 bil.gal. of water daily to that area from the Colorado River 242 mi. away. This project cost about $220,000,000 and is now operating successfully, even though it is necessary to lift the water 1,600 feet. On the eastern seaboard, the states of New York, Pennsylvania, New Jersey and Delaware combat a paramount stream pollution problem along the Delaware River, which has been used as an open sewer since the settlement of the region. The "Physical Facts" report of the Interstate Commission on the Delaware River Basin shows that

* "Frontinus and the Water Supply of the City of Rome," by Clemens Herschel, p. 239.

the Trenton-Philadelphia area discharges more than 400 mgd. of raw sewage into the Delaware River from which the public water supplies of these cities are obtained.

The network of streams bordering and crossing the four states of the Southwest have affected the development of the area in many respects. At the turn of the century, little effort had been made to utilize intelligently the water resources of the southwestern region. Major streams were used for navigation, if conditions permitted, but no reservoirs of consequence had been constructed to impound water for use during drought periods. Some under-designed levees had been constructed. What was then considered a major dam and hydro-electric plant on the Colorado River at Austin, Tex., the cost of which was over $600,000, was destroyed by a moderate flood in 1900. It may be true that the economic condition of the country at that time did not justify the construction of large works for the most efficient use of water. However, man continued to till the soil in the flood plains and to construct small structures to harness or divert water from the streams only to see his efforts come to naught in a few years. Practically no factual data were available to reveal the variations in flow, peak rates of flow, lengths of droughts, and other important runoff data upon which the engineer could base a structurally sound design, properly correlated with an economical investment. It is not surprising, therefore, that failures frequently occurred. Factual stream flow data that are used in the design of present-day developments eliminate many uncertainties in construction and operation features. The Pensacola Dam on the Neosho River creates a reservoir with a capacity of 1,612,000 acre-ft.; Denison Dam and reservoir (the largest of the southwestern region) on Red River, impounds 5,818,000 acre-ft.; and the multiple-dam construction on the lower Colorado River of Texas, which provides a total storage of 3,000,000 acre-ft., are some of the new developments of the southwestern region that help control, conserve and properly utilize the surface water resources.

The 430,000 sq.mi. of the southwest region where 13,000,000 people are living might be termed an empire in its own right. From west to east, it extends from the eastern slopes of the Rocky Mountains to the Mississippi River, spanning 18 deg. of longitude; and from south to north, from the Gulf of Mexico to the central portion of the United States it spans 12 deg. of latitude. Climatic conditions range from a humid semi-tropical climate along the Gulf of Mexico to a dry and comparatively cold climate in the northwest portion. The average annual rainfall ranges from 8 in. near El Paso, Tex., to 60 in. on the Mississippi Delta. The wide range in climatic conditions, coupled with broad and abrupt changes in topography, surface soils and vegetation cover, provide an unlimited variety of streams and surface runoff.

This highly productive region, representing one-seventh of the area of the United States, is now not only the nation's source of a large variety of agricultural products, livestock and timber, but is an important producer of oil, sulfur and other strategic minerals vital to present-day standards of living. Magnesium, bromine and other chemicals are extracted from the salt waters of the Gulf of Mexico; synthetic rubber is manufactured from oil and agriculture products; iron, coal, aluminum and mercury are produced in large

quantities; potash, sodium sulfate and other chemicals are mined from the Permanian red beds of northwest Texas; paper is manufactured from low-grade timber grown in the four states of the region; and chemurgy promises an outlet for large quantities of agricultural products. The importance of water and electric power in the production of these items is indicated by the fact that during the past three years the U.S. Geological Survey furnished water resources reports to the War Department and related agencies in the following quantities: Arkansas, 114; Louisiana, 259; Oklahoma, 225; and Texas, 1,224.

In the 50-year period, 1890–1940, the population of Texas increased 287 per cent. Water demands increased 7,000 per cent during the same period.

Rainfall

The major portion of the rainfall in the southwest region comes from maritime air masses which form over the Gulf of Mexico. Occasionally, though rarely, rainfall for this area comes from air masses that form over the Pacific Ocean and pass over a mountain range to reach the region. Louisiana and Texas, contiguous to the Gulf of Mexico, lie in the path of tropical or semi-tropical storms that enter directly from the Gulf. Such storms are, at times, the source of intense rains. A rainfall exceeding 20 in. in 24 hours is not a particularly rare occurrence in the southern portion of these two states. The U.S. Weather Bureau records show 23.11 in. in 24 hours at Taylor, Tex., on Sept. 9–10, 1921. Unofficial reports of this storm indicate that as much as 30 in. of rain fell in about fifteen hours. Unofficial but reliable information shows that at least 20 in. of rain fell in a period of about three hours at the Woodward Ranch on Seco Creek, west of San Antonio, Tex., on May 31, 1935. The northwestern portion of the region may seem to be arid, but on June 15, 1938, a storm occurred in Donley County of the Texas Panhandle that produced 14 in. of rain in a one-day period. The Cleveland, Okla., vicinity experienced a similar rain in May 1940. Unofficial information indicates that 21 in. of rain fell on that far inland community in 24 hours, and the resulting flood overtopped and seriously damaged Cleveland's water supply dam.

The 97th meridian practically divides this four-state region. To the east lie the extreme eastern portions of Oklahoma and Texas, and all of Arkansas and Louisiana. The average annual rainfall not far to the east of the meridian is 36 in., which is the yearly average rainfall for the entire four-state region. The average increases eastward to 50 in. in Arkansas and 60 in. in Louisiana. To the west of the 97th meridian, rainfall decreases to an annual average of 22 in. at the western edge of Oklahoma, and to only 8 in. near El Paso, Tex. U.S.G.S. Water Supply Paper 820, "Drought of 1936," page 52, reports that precipitation near the eastern borders of Arkansas and Louisiana has been less than consumptive requirements of evaporation and transpiration for only 2 per cent of the time. The deficiency increases to 40 per cent near the 97th meridian, and increases westward to El Paso where the precipitation has been less than the normal requirements for 100 per cent of the time.

Although eastern Oklahoma and Texas, and all of Arkansas and Louisiana, lie well within a humid region, portions of these areas suffer from droughts at times. In May 1943,

northeastern Oklahoma and western Arkansas experienced some of the most damaging floods in their history. The Arkansas River at Ft. Smith, Ark., reached a peak stage of 41.7 ft. on May 23, 1944, or 3.7 ft. higher than the historical flood of 1833. The Water Resources Division of the Oklahoma Planning and Resources Board estimated the flood losses to be $19,500,000 in that state alone. Even though May 1943 was one of the wettest months known in Arkansas, it was followed by a severe drought which lowered the state's average rainfall for that year to 35.01 in.—a near minimum of record. The year was the driest since 1936 and the second driest on record. The normal annual rainfall for Arkansas is 48.97 in.

Runoff

About one-sixth of the 36-in. average annual rainfall of this four-state region appears in the streams as runoff. The yield, of course, varies widely within the region, ranging from less than 1.0 in. in western Texas and Oklahoma to 15 in. in Arkansas and 20 in. in southeastern Louisiana. The actual runoff from year to year, however, deviates widely from the average. All sections of the region have experienced extended droughts and excessive rainfall. In the west some streams draining thousands of square miles will remain dry at times for two or more months, and smaller areas of the eastern, or humid section of the region will yield useless quantities of surface runoff for periods of 30 days or more.

The average annual runoff from within the borders of the four-state region is about 135,000,000 acre-ft. (44 trillion gallons per year)—more than enough water to supply one billion people with 100 gal. daily. If this runoff were uniformly distributed in respect to time and area, water supply problems in all sections would be simplified. Unfortunately, nature has not provided a uniform distribution of the surface waters and as a result, some sections of the region suffer from water shortage and others are troubled with damaging overflows. Table 1 shows results of distributing this average annual runoff by states.

Considering each state as a unit, it is interesting to note that it takes 6.7 sq.mi. in Texas to produce a runoff equal to that from 1 sq.mi. in Louisiana. Oklahoma needs 4.3 sq.mi. and Arkansas 1.5 sq.mi. to equal the Louisiana runoff.

The above runoff values do not include flow which originates outside the region but which contributes to its border or traversing streams, such as the White River of Arkansas, Mississippi, St. Francis, and Canadian rivers and the Rio Grande.

The Mississippi River at Vicksburg, Miss., above the mouth of Red River, drains 1,144,500 sq.mi., and its average annual runoff is 368,000,000 acre-ft., or nearly three times that draining from the four states of Texas, Oklahoma, Arkansas and Louisiana. The combined average annual runoff from those portions of the St. Francis, White and Arkansas rivers and the Rio Grande lying outside of the region is about 10,000,000 acre-ft.

The combined average annual runoff of all the streams within the four states and bordering thereon is about 500,000,000 acre-ft., draining from an area equal to about one-half that of the entire United States.

The principal rivers of the region, with their average annual discharge and extremes of discharge, are shown in Tables 2 and 3.

TABLE 1

State	[1] Drainage Area, *sq. mi.*	[2] Average Yearly Run-off, *acre-ft.* (approx.)	Average Yearly Run-off, *acre-ft. per sq. mi.*	Average Yearly Run-off, *mil. gal. per sq. mi.*	[3] Average Annual Rain-fall, *in.*	Average Annual Run-off, *in.*
Louisiana	45,409	45,000,000	990	323	55.64	16.9
Arkansas	52,525	35,000,000	666	217	48.97	12.3
Oklahoma	69,414	16,000,000	230	75.3	32.63	4.3
Texas	262,398	39,000,000	149	48.6	30.84	2.9
Total	429,746	135,000,000				
Average			314	102	35.97	5.7

[1] Land area—Rand McNally Commercial Atlas. [2] Determined from National Resources average annual runoff chart. [3] Values from Geological Survey Water Supply Paper 820.

Considering the area drained and the total runoff, the Mississippi River is the largest river in the United States. It forms the eastern border of Arkansas and part of the eastern Louisiana border. The flow is always more than is needed; in some respects it is a detriment to the region in that its major floods destroy hundreds of thousands of acres of agricultural crops and other property. Flood control, the major problem along this river, will not be mastered until flood control reservoirs are constructed for regulating the flow at all practical sites in this great basin and adequate levees constructed and properly maintained to confine the reduced but large flood flows that will continue to occur.

In drainage area only, the Rio Grande is the second largest river in the southwest region. The International Boundary Commission (United States and Mexico) makes the following statement in Water Bulletin No. 12, page 96: "The total area within the outer rim of the Rio Grande Basin is about 335,500 sq.mi. But, in many places, and particularly along the southwestern side of the basin (Mexico) large areas yield no runoff to the Rio Grande. Such non-yielding areas constitute about 48.8 per cent of the total area encompassed by the outer rim of the basin leaving 171,643 sq.mi. of productive watershed." The average annual rainfall for the basin is probably less than 15 in. and limits the runoff to a comparatively low quantity. The lower-river runoff is further reduced by large diversions for irrigation at and above El Paso, Tex., and on the upper reaches of the Pecos River, a tributary. Elephant Butte Reservoir, upstream from El Paso, controls the up-river flow and the water is consumed primarily in irrigating lands in that vicinity. Reservoirs on the Conchos, Salado and the San Juan, tributaries from Mexico, partly regulate these flows, some of the water being used for irrigation. The average annual runoff of the Rio Grande below the San Juan and at the upper end of the famous lower Rio Grande Valley, is 5,000,000 acre-ft., of which one-tenth, or a major portion of the river's low flow, comes from large springs discharging from the Edwards limestone in the Langtry-Del Rio, Tex.,

area. Without this uniform and dependable flow, the 500,000 Texas acres of irrigated land in the lower river would suffer more frequent water shortages.

Irrigation is widely practiced throughout the Rio Grande basin. According to publications of the International Boundary Commission (Bulletin No. 12, page 97), the National Resources Committee report (Regional Planning-Upper Rio Grande Basin), and the National Resources Planning Board report (Regional Planning-Pecos River basin), 2,400,000 acres are under irrigation. Of this acreage, 752,000 acres lie in Texas, 613,000 in Mexico, and the remainder in New Mexico and Colorado. Thus, the limited water supply of the basin is working double time. The storage of additional flood waters throughout the basin would permit the expansion of irrigation and the installation of some hydro-electric plants and would reduce flood menaces in some areas, especially those that are irrigated.

Considering runoff, there are many streams in the four-state region that exceed the Rio Grande. In Texas, the Sabine River, draining 9,440 sq.mi. at Ruliff, has an average annual runoff of 6,000,000 acre-ft. (the largest of all Texas streams except Red River). Runoff from the Trinity and Brazos rivers exceeds that of the Rio Grande. The Arkansas River at Little Rock, Ark., has more than five times the runoff of the noted international-boundary stream. The White River at De Valls Bluff, Ark., and Red River at Garland, Okla., each yields more than twice that of the Rio Grande, and the Neosho River at Wagoner, Okla., draining 12,500 sq.mi., yields slightly more water than the Rio Grande. The Canadian River at Whitefield, Okla., draining 47,400 sq.mi. (one-third of the Rio Grande drainage area) lying mostly in an arid and semi-arid region, has an average annual yield of about 4,600,000 acre-ft., or about 90 per cent of that of the Rio Grande.

Although the runoff at each of the above mentioned rivers, except the Canadian, is greater than the Rio Grande, the minimum recorded flows show that, except for White River, the minimum of 946 cfs. at Rio Grande City, Tex., in 1940 was materially greater than the minimum of 850 cfs. of the Arkansas River at Little Rock, Ark., in 1934, and of other streams used in this comparison.

In drainage area, the Arkansas River is second to the Rio Grande. Above Little Rock, it drains 157,900 sq.mi. It is interesting to note that the headwaters of these two streams originate above an elevation of 10,000 ft. on the mountain divide in south-central Colorado. From there the Rio Grande's course is first south and then southeast, through an arid or semi-arid belt, to the Gulf of Mexico. The Arkansas River's course from this mountain region is first to the east into Kansas, traversing a semi-arid region, and then southeast through a sub-humid and humid region to the Mississippi River above Greenville, Miss. The watershed of the Arkansas River, lying in the states of Colorado and above Garden City, Kan., encompasses 28,800 sq.mi. From this comparatively large area the average annual runoff is only 184,000 acre-ft., as compared with the Rio Grande's average yield of 1,100,000 acre-ft. from its watershed of 27,700 sq.mi. above San Marcial, N.M. Downstream from Garden City, Kan., the runoff of the Arkansas River increases rapidly and near the Kansas-Oklahoma state line, the annual runoff

TABLE 2

Large Streams	Location	Period of Record	Drainage Area *sq.mi.*	Average Discharge *cfs.*	Average Daily Discharge *gal. per sq.mi.*	Maximum Discharge		Minimum Discharge	
						cfs.	*Year* [a]	*cfs.*	*Year*
Mississippi	Vicksburg, Miss.	1931–42	1,144,500	509,900	288,000	2,080,000	1937	99,400	1940
St. Francis	Marked Tree, Ark.								
White	De Valls Bluff, Ark.	1927–42	23,430	23,410	646,000	151,000	1937	3,200	1936
Arkansas	Little Rock, Ark.	1927–31, 1933–42	157,900	37,710	154,000	536,000	1943	850	1934
Cimarron	Oilton, Okla.	1934–42	17,700	1,110	40,500	72,300	1935	0	1936
Verdigris	Claremore, Okla.	1935–42	6,520	3,300	327,000	182,000	1943	0	At times
Neosho	Wagoner, Okla.	1924–25, 1937–42	12,400	7,340	383,000	400,000	1943	210	1939
Canadian	Whitefield, Okla.	1938–42	47,370	6,376	87,000	281,000	1943	65	1940
North Canadian	El Reno, Okla.	1938–42	12,100	320	17,100	15,000	1941	0	At times
Red	Garland, Okla.	1927–31, 1934–42	51,500	17,590	221,000	327,000	1938	400	1931
Red	Alexandria, La.	1938–42	65,900	—	—	210,000	1908	1,180	1934
Washita	Durwood, Okla.	1928–42	7,310	1,490	132,000	91,300	1943	17	1934
Ouachita	Monroe, La.	1938–42	15,400	—	—	60,800	1939	[b]382	1939
Sabine	Ruliff, Tex.	1924–42	9,440	8,243	564,000	76,600	1935	338	1939
Neches	Evadale, Tex.	1904–06, 1923–42	7,908	6,295	514,000	175,000	1884	148	1925
Trinity	Romayor, Tex.	1924–42	17,190	7,652	288,000	111,000	1942	132	1925
Brazos	Richmond, Tex.	1903–05, 1922–42	44,050	8,099	119,000	120,000	1929	33	1934
Little	Cameron, Tex.	1917–42	7,034	1,998	183,000	647,000	1921	2.6	1918
Colorado	Columbus, Tex.	1904–11, 1916–30, 1939–42	40,840	3,373	53,400	190,000	1935	80	1910
Guadalupe	Victoria, Tex.	1935–43	5,676	2,017	230,000	179,000	1936	[c]308	1939
Nueces	Three Rivers, Tex.	1915–18, 1920–42	15,500	850	35,400	85,000	1919	0	At times
[d]Pecos	Comstock, Tex.	1924–42	35,243	533	8,980	116,000	1932	97	1930
[d]Rio Grande	Rio Grande City, Tex.	1932–42	171,000	7,300	27,600	—	1909	946	1940

[a] Through 1943, or historical peaks if discharge has been determined.
[b] Minimum recorded; lower discharge probably has occurred.
[c] Daily.
[d] From Water Bulletin No. 12, U. S. Dept. of State, International Boundary Commission, United States and Mexico.

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TABLE 3

Small Streams	Location	Period of Record	Drainage Area *sq.mi.*	Average Discharge [c] *cfs.*	Average Daily Discharge *gal. per sq.mi.*	Maximum Discharge		Minimum Discharge	
						cfs.	*Year* [a]	*cfs.*	*Year*
White	Beaver, Ark.	1909–10, 1923–42	1,238	1,507	790,000	65,000	1927	3.0	1936
North Fork	Henderson, Ark.	1928–42	1,612	1,423	570,000	61,000	1943	312	1936
Chikaskia	Blackwell, Okla.	1937–42	1,690	309	118,000	100,000	1923	0.5	1940
Council Creek	Stillwater, Okla.	1934–42	30.2	9.9	212,000	18,000	1942	0	At times
Wolf Creek	Fort Supply, Okla.	1937–42	1,460	104	46,000	14,200	1939	0	At times
Petit Jean Creek	Danville, Ark.	1916–42	760	795	670,000	70,800	1939	0	At times
Cache Creek	Walters, Okla.	1938–42	630	142	146,000	11,300	1941	0	At times
Little Wichita	Archer City, Tex.	1932–43	496	118	154,000	17,900	1941	0	At times
Kiamichi	Belzoni, Okla.	1926–31, 1935–42	1,420	1,556	710,000	83,700	1938	0	At times
Little	Horatio, Ark.	1931–42	2,690	3,638	870,000	110,000	1938	1.0	1934
Sulphur	Darden, Tex.	1923–43	2,754	2,094	490,000	92,900	1938	0	At times
Saline	Rye, Ark.	1937–42	2,040	2,412	760,000	42,300	1938	9.8	1938
Dugdemona	Jonesboro, La.	1938–42	351	438	810,000	16,600	1942	3.9	1939
Amite	Denham, La.	1938–42	1,330	1,590	780,000	20,800	1940	279	1938
Calcasieu	Oberlin, La.	1922–24, 1938–42	753	1,420	1,220,000	34,700	1923	42	1924
Angelina	Lufkin, Tex.	1923–34, 1939–43	1,575	1,243	510,000	38,200	1932	2.3	1939
Village Creek	Kountze, Tex.	1924–27, 1939–43	837	968	740,000	67,200	1940	9.9	1943
East Fork Trinity	Rockwall, Tex.	1923–43	831	452	350,000	—	1922	0	At times
San Jacinto	Huffman, Tex.	1936–43	2,791	1,908	440,000	253,000	1940	49	1939–40
Clear Fork Brazos	Crystal Falls, Tex.	1928–43	5,658	542	62,000	35,800	1941	0	At times
N. Llano	Junction, Tex.	1915–43	914	77.8	55,000	94,800	1936	0	At times
Frio	Concan, Tex.	1923–43	485	115	155,000	162,000	1932	8.1	1928
Atascosa	Whitsett, Tex.	1924–26, 1932–43	1,171	160	90,000	39,300	1942	0	At times
Madera Canyon	Toyahvale, Tex.	1932–43	54	5.0	58,000	5,120	1932	0	At times

[a] Through 1943, or historical peaks if discharge has been determined.

is 930,000 acre-ft., draining from 44,700 sq.mi. At Little Rock, Ark., 157,900 sq.mi. of drainage area produces an average annual yield of 27,000,000 acre-ft.—a quantity equal to two-thirds of that coming from all of Texas.

White River, heading in the Ozark Mountains of northwestern Arkansas, flows northeast into Missouri and from there it follows a southeasterly course back into Arkansas and on to the Mississippi River southeast of Little Rock. It lies entirely within a humid climate, thus producing a substantial runoff throughout its course. At De Valls Bluff, Ark., the average annual runoff is about 17,000,000 acre-ft., and the minimum recorded flow is 3,200 cfs.

Red River is the largest stream lying entirely within the four-state region. It heads on the high plains of the Texas Panhandle, moving eastward from this semi-arid region to the Mississippi River southeast of Alexandria, La. Although the surface water yield is small in the headwaters, the average annual runoff from the 51,500 sq.mi. above Garland, Okla., is 13,000,000 acre-ft., second only to the White River of northern Arkansas.

The Salt Fork of the Arkansas, the Cimarron, Verdigris, Neosho, Canadian, North Canadian, Washita and Kiamichi rivers within the borders of Oklahoma; and the St. Francis, Black and Ouichita rivers of Arkansas, are all streams of considerable consequence.

Within the borders of Louisiana, the Red and the Ouichita, other than the Mississippi and its numerous channels, are the two largest streams. Reliable records of stream flow are of too short duration to reveal the actual yield which is known to be substantial in that humid region.

Most streams of Texas originate within its borders. The Rio Grande and the Red River form part of the state's southern and northern borders; the Canadian traverses the Panhandle region, and the Sabine forms the southern portion of the eastern boundary. The greater part of Texas's population is not in the watersheds of those boundary or interstate streams; therefore, Texas must look primarily to the watersheds of the Neches, Trinity, San Jacinto, Brazos (largest in Texas, drainage area, 44,000 sq.mi.), Colorado, Guadalupe, Nueces rivers and smaller coastal streams for its surface water supply. All of these streams head in and traverse semi-arid or subhumid sections except the Neches River which lies entirely within the humid region of east Texas. Surface flows of these streams are erratic but the average runoff is substantial and, if properly controlled and utilized, will provide water supplies for major industrial, hydro-electrical and irrigation expansions throughout the state.

These Texas streams and tributaries present the designing engineer with probably a larger variety of economic problems than any other section of the four-state region. Except for the Neches River in east Texas, the rates of flow vary widely and quickly as the result of rainfall from tropical or semi-tropical storms. This is especially true of streams draining the Edwards Plateau in central Texas. A number of recorded peak discharges in this section far exceed those recorded in other equal areas of the United States. The greatest of these was the flood of 1935 on the West Nueces River near Brackettville, Tex., when the discharge was 580,000 cfs. from 402 sq.mi., which is larger than the historical peak flow of the Arkansas River at Little Rock, Ark., in May 1943, when the discharge was 536,000 cfs. The peak discharge

of the Arkansas River in 1943 was larger upstream from Little Rock, reaching 850,000 cfs. at Van Buren, Ark. These peak flow rates of Texas streams last but a short time, usually less than one hour, and the total volume of runoff usually is not large. A heavy rain fell over a portion of the Pedernales River basin in central Texas on Aug. 30, 1944. The flow of the Pedernales rose from less than 200 cfs. early that morning to 120,000 cfs. at noon and dropped rapidly back to a few hundred second-feet the next day. Excessive peak rates of runoff of a lesser degree have been recorded throughout the region. 1940 records in northeastern Oklahoma show some unusually high rates of runoff in that state. On Sept. 4, 1940, Ranch Creek near Hallett, Okla., had a peak discharge of 32,400 cfs. from 17.1 sq.mi. Similar runoff rates were recorded on other streams in that section.

Water Uses

A few months ago one of the national magazines published an article concerning industrial water demands and the overtaxing of water supplies in the Ohio River Valley and other industrial sections of the North and East. The article pointed out that 18,000 gal. of water is needed to produce one ton of ingot steel. One steel mill uses 500,000 mil.gal. of water a year and, at times, raises the temperature of its river supply to 130 deg. The article stated that water supplies in these humid regions were being overtaxed and corrective measures must be inaugurated to provide water of sufficient quantity and quality to the users.

The Southwest has not yet experienced so severe an industrial water shortage. Industry, however, is rapidly moving into the region where possibly $2,000,000,000 has been spent on new industrial plants within the past four years. These plants include iron, tin and zinc smelters; steel mills and synthetic rubber plants; airplane factories; chemical and magnesium plants; and other essential new developments. Some of these plants have already placed a heavy draft on the flow of unregulated streams as well as on the ground water supply with a water use in some areas in excess of that predicted for twenty years hence. An iron smelter recently completed requires 17 mgd. of water and should a proposed steel mill be erected in conjunction with the iron smelter, the daily water demand will increase to 70 mil.gal. Some industrial plants were not constructed because an ample water supply was not readily available.

The water requirements for some of the other industries are of interest. The manufacture of one ton of liquified ammonia requires 31,000 gal. of soft water. Viscose rayon uses 100 gal. per lb. of yarn. One ton of paper requires from 5,000 to 170,000 gal. of water. One process of synthetic rubber production requires 85,000 gal. per ton of rubber. For each gallon of aviation gasoline, about 25 gal. of condensing water is needed. The cooling system of a large Texas airplane factory circulates 20 mil.gal. of water daily. About 100 gal. of water is needed to produce 1 lb. of powder. A Texas brewery needs 1,250 gal. of processing water for the manufacture of one keg of beer.

Texans are now irrigating approximately 1,200,000 acres of land, the major portion of which is dependent upon the natural flow of streams. The people of Louisiana and Arkansas are irrigating thousands of acres of rice land, and Oklahomans are irrigating a

variety of crops to a lesser extent. The 13,000,000 people of the region need about 800 mgd. for domestic uses.

All parts of Texas and Oklahoma are faced with water shortages at times. Communities of Arkansas and Louisiana, which depend upon some small streams for water, also experience shortages at times. The people of Texas and Oklahoma are definitely concerned with the conservation of water for beneficial use in all sections and the control of flood flows along the major rivers. Arkansas and Louisiana are concerned with controlling and utilizing flood waters, conservation of water in small areas of the higher lands, and the draining of swamps. The construction of hydroelectric plants will be an integral part of the majority of these developments.

This great southwestern region is only partly developed. Its wealth of natural resources and its proximity to world markets, provide opportunities for future expansion. The limited water resources in Texas and Oklahoma will determine the ultimate development in these states, as well as a number of sections of Arkansas and Louisiana. It is essential, therefore, that the waters of the entire region be properly conserved and controlled, and that the quality and temperature of water be preserved for beneficial use of the entire region.

Present-Day Scope of Pitometer Surveys

By E. Shaw Cole

Chief Engr., The Pitometer Co., Inc., New York, N.Y.

Presented on Nov. 4, 1944, at the New Jersey Section Meeting, Atlantic City, N.J.

AT the beginning of the war, the water supplies of many communities were overtaxed by the unforeseen abnormal demands put on them by industries engaged in the manufacture of war materials, as well as by the large populations concentrated suddenly near these industries. As a result the desire to know everything about the distribution system became greater than ever before. Where was the water going, why and how? Could the demand be reduced by controlling waste from all sources? Had the increased demand created excessive velocities causing pressure drops that could be relieved by intelligent study of flow conditions, leading to the design of extensions and replacements?

In referring to a paper presented before the New England Water Works Association in 1943, entitled "Application of the Pitometer to Water Distribution Systems," a well-known engineer, formerly superintendent of a large system, said that this was the first time he had seen emphasis placed on features of the pitometer water waste survey that he considered as important as, if not more important than, the actual leakage located. He stated further that the general information gained and the detailed check on the operation of the system was of great importance to any water works operator.

It has been suggested that a pitometer survey be compared with a complete medical and physical examination such as would be made in a clinic. Various measurements would be made to determine the physical condition of the patient. The type of tests, the equipment and the technic have all been improved over the years, and, while these have probably resulted in better diagnosis, the basic tests have not been changed greatly. So it has been with the pitometer survey. Years ago the pitometer was called the x-ray of water works systems. Although new tools have been provided and technics improved to increase the efficiency of the survey, the basic flow measurements developed years ago are still important and valuable.

To carry the medical analogy one step further, let us consider that the counterpart of the general practitioner or family doctor is the water works superintendent or local engineer. While these men do splendid work and in some cases operate for years without any outside help or advice, it is quite common for a progressive doctor to send a patient to a clinic for a complete physical and medical examination. At the clinic are to be found doctors trained in this type of work—men who specialize in a particular field and for this reason excel in it. The need for an organization of engineers which specializes in conducting pitometer surveys and can be called on at any time to help in whatever way is

desired, whether it be for a short test or a complete survey, is somewhat similar to the need for clinics. Perhaps this need is best illustrated by the fact that during the last five years, the author's firm has conducted a total of 251 surveys and tests in 159 different communities. The majority of these were water waste surveys that covered approximately 12,000 mi. of mains. This work resulted in the location and repair of over 6,500 hidden underground leaks wasting a total of 106 mgd. At an average purchase or production cost of five cents per 1,000 gal., this amount of water represents an annual saving of $1,935,000.

While the judgment of federal agencies is not necessarily the best criterion, it is interesting to note that the 251 surveys and tests included work for four large Navy shipyards, as well as for several cities where the FWA thought it sound practice to have a survey made before approving grants for expensive extensions and reinforcements. The federal government of one of our neighboring countries also authorized a pitometer survey in one of its cities, as the quickest and most economical means of obtaining an adequate supply for one of its largest arsenals. Also included are tests for important war plants, including a government arsenal, airplane manufacturing plants and oil refineries.

The pitometer survey is an engineering operation divided into two definite fields:

1. An accounting for all the water delivered to the distribution system, known as the water waste survey.

2. An engineering study of the existing distribution system to improve distribution facilities.

While the primary object of the pitometer water waste survey is to locate underground leakage, its scope is very much broader than this. The operations may be divided as follows:

1. Test of pumps for slip or efficiency.

2. Measurement of the flows at either end of gravity supply lines to determine leakage.

3. Measurement of the flow in and out of reservoirs to determine leakage.

4. Test of master meters for accuracy.

5. Measurement of the flow to various districts of the city. A study of the night rate of flow and its relation to the total, indicates the existence of leakage. Also, the information obtained is the basis for future design and extensions and replacements in a distribution system.

6. A test of large industrial meters and a check on industries for unauthorized use of water.

7. Night subdivision, or the analysis of the night rate of flow in districts where waste is indicated, which results in the measurement of the flow in every block or between every set of valves.

8. Location of underground leakage. By this method of night subdivision, every underground leak in the system large enough to justify the cost of repair is indicated by measurement and its exact location determined by the use of sound intensifiers.

9. House-to-house inspections, based on the result of night subdivision, are carried out for the purpose of controlling leaking plumbing fixtures in unmetered systems. In metered systems, the measurements provide indications of under-registration of domestic meters.

10. Special tests that include such things as river-crossing tests, industrial tests and measurements not mentioned above.

Not all surveys result in spectacular findings in each of these steps but the following examples are not as unusual as might be supposed, and some of them have been recently encountered in otherwise well-operated systems.

Pump Tests

The logical starting point of any engineering project of this kind is the source of supply. In the early days where the supply was pumped, a test to determine the slip of the reciprocating pumps frequently showed amazing conditions. In some cases where maintenance was entirely absent, slip ran as high as 80 to 90 per cent, as could be demonstrated by shutting the discharge valves practically to the closed position without raising the discharge pressure.

As reciprocating pumps have been replaced by centrifugal pumps, the pump tests have come to include wire-to-water efficiency tests. These, too, sometimes show surprising conditions, as described in an excellent paper by H. E. Beckwith, entitled, "A Simple Method of Testing Centrifugal Pumps" (Jour. A.W.W.A., **31**: 2098 (1939)). According to Beckwith, it is not unusual to find a centrifugal pump which is operating under an entirely different set of conditions than that for which it was designed. He cites a recent test that gave a wire-to-water efficiency of only 40 per cent. The savings resulting from the installation of a pump designed to meet the operating conditions were very substantial.

Supply Lines

In gravity systems, the starting point for the survey is the reservoir and the gravity supply lines it feeds. A test of the gravity supply lines is made by measuring the flow at the inlet and at the outlet and, at the same time, leakage from the reservoir is determined by measuring the rise and fall in the reservoir, adjusted for the flow in or out, as the case may be. Where a long gravity supply line crosses rough and marshy country and possibly a river, it is important to know by direct measurement that there is no appreciable underground leakage. The approximation of accuracy by any hydraulic instrument in the field is not much greater than 100 ± 2 per cent. In large gravity lines, a small loss could go undetected, due to the allowable error of the measurements. At the same time it should be pointed out that many losses have been detected where the difference between the inlet and outlet quantities did not exceed 3 to 4 per cent. In a recent survey for a small New Jersey system, a measurement of the flow in each end of a gravity line, 7 mi. long, showed discrepancies of 30 per cent between the reservoir and the town. The demands of this system had gradually increased over a period of years until it became necessary to install a booster pump in order to maintain an adequate supply. After the original discrepancy had been detected, intermediate gagings were made to localize the section where the loss occurred. Sound intensifiers were then used with positive assurance that leakage existed and a blown joint, which was wasting 250,000 gpd. into a large swamp, was quickly discovered.

Master Meter Tests

The testing of master meters for accuracy is a routine step that is necessary if figures on unaccounted-for water are to be used as the criterion for efficient operation and the absence of lost water. In the case where water is purchased through a master meter this

test has a real dollar value and in two New Jersey communities that readily come to mind, substantial savings resulted from the discovery that the meters were over-registering. In one case it was not thought possible that the particular meter in question could over-register and only after repeated checks and conferences did all parties concerned accept the result of the original test. In this case there was an overcharge of 16 per cent. In the other instance, it was found that the flow through the master meters reversed during the night hours. Because the type of meter used registered positively, regardless of the direction of flow, this community was charged twice for water that was never used—once when it entered the system and again when it left it.

District Measurements

The division of a system into districts and the measurement of the flow into each district for a period of at least 24 hours provides information that is not only of value in indicating the existence of underground leakage, but gives valuable information regarding the operation of the entire distribution system. Primarily the district measurements are made so that the night rates of flow may be studied. The actual size of the district will vary but usually includes from 8 to 10 mi. of main and may be as large as 30 mi. A high flow at night of over 30 per cent of the total in the residential section of a metered system indicates the possibility of leakage and justifies further investigations, while a 40-per cent night rate is a sure indication of leakage or waste of some kind. However, a low ratio of night flow to the total flow indicates that it would be uneconomical to make further investigations.

In the many cities where more than one survey has been made, a comparison with results of the previous district measurements provides a more exact means for predicting the existence of leakage. Some of our larger cities, notably Philadelphia, Pittsburgh, Rochester, Boston and Cincinnati, have found it economical to have a certain amount of work done each year, so as to keep their waste down to a minimum. The district measurements are an important part of these annual surveys, for in this way it is possible to cover a tremendous number of miles quickly by eliminating the many sections that are invariably found to be tight, and then to concentrate detailed investigations in areas that are definitely known to contain waste or leakage. In this connection it should be noted that the over-all accounted-for figures in large systems, where the consumption may be 30 to 40 mgd. or greater, are subject to so many variables with regard to consumption that it is not as easy to detect the presence of underground leakage as it is in a small compact system. A change of only a small percentage in a large system can involve more water than the entire consumption of the small system.

By isolating the districts by means of closed valves, so that the feed may be supplied through one or more large mains on which the pitometer is installed, it is possible to learn a good deal about the operation of the trunk mains. Pressures are taken before and after the district is isolated. The flows are studied and the adequacy of existing feeds taken into consideration, so that in case of fire there will be ample supply until the key boundary valves are opened in accordance with arrangements made between the fire and the water departments.

In a recent survey the formation of the district boundaries proved to be a difficult operation, due primarily to the condition of the valves and errors in the map. The time involved in solving the problem, however, proved to be well worth-while for the city because two of its important feeders were found to be carrying no water. Investigation showed that one 12-in. valve was closed, one double-check valve was frozen closed and one 12-in. valve was partly closed. The latter discovery explained the reason for inadequate pressures during a recent fire.

In another system there was a high area that had suffered from low pressures for years. When district measurements were being made at the start of a survey it was found that the principal feed, a 20-in. main, carried no water because of a 20-in. valve that was closed and too stiff to operate. In addition to these not infrequent discoveries, the district measurements always provide information regarding the consumption in the various sections of the system that are of value as a basis for designing extensions or reinforcements to the distribution system.

Industrial Meter Tests

Improved meter practice and close supervision of industrial consumers has greatly reduced the loss of water in many systems, but there are still a large number of meter departments which do not make complete checks on the accuracy of the large meters and the use of water passing through them and through fire lines.

The advantages of testing large meters in place and under operating conditions, with the pitometer, may not be apparent to those meter superintendents who periodically use a test meter to check their meters. While it is true that there are some systems where the meters are in excellent condition, within three weeks two cases of under-registration involving large quantities of water were brought to light during routine field tests. In one large eastern city, a fire line meter was tested in spite of the fact that it showed no registration and that the factory said they were not using any water through it. The test showed that there not only was a flow but it was so large that a continuous test was run for a week. The average under-registration for this period was 427,000 gpd. and the rate varied from zero to a maximum of 1,660,000 gpd. through a 6-in. pipe, or a velocity of over 13 fps. Four hundred and twenty-seven thousand gallons per day is not only a lot of lost water, but at a meter rate of ten cents per 1,000 gal. the lost revenue amounts to over $15,000 a year.

In a midwestern city in the course of a routine test of a large industrial meter, the pitometer was installed upstream from the meter and bypass. The measurement showed the meter to be under-registering an apparent 200,000 gpd. On the bypass, however, there was an unmetered fire line that supplied yard hydrants and sprinklers and fed a fire tank. Investigation showed that there was continuous use from the fire line and when it was stopped a re-test of the meter showed the meter to be correct. In this case considerable revenue will be received as a result of back billing, and the future loss of revenue will be stopped. A number of years ago it was possible for one city to recover over $200,000 because of unauthorized and unmetered use by one plant. One may say the existence of these conditions is inexcusable but when the details of each case are known, it is easy to see how

the condition developed and how it was overlooked for so long a period. This is merely another illustration of the advantage of flow measurements and a complete checkup on where the water is going.

Night Subdivision and Leak Location

Following the 24-hour district measurement comes the problem of locating all underground leakage. If the night rate of flow warrants further investigation, the district is then subdivided at night by measuring the flow in every block or between every set of valves. The importance of these measurements cannot be over-emphasized, because only in this way is there a *positive* indication of the existence of underground leakage. This whole subject could and has been discussed at great length.

The location of leaks has been a common occurrence in every water works since the first leak patrols were organized in England over 100 years ago and perhaps long before that. The main point to be emphasized here is the difference between the leak patrol or listening type of survey and the pitometer survey. By the periodic use of sound intensifiers leakage can be and is controlled by almost every water works plant. This type of control is excellent practice and should be encouraged. At the same time it should be recognized that this method is in a sense a negative control, *i.e.*, if no noise is heard on a main or its connections, it is concluded that there is no leakage; or if a slight noise is heard, and further investigation does not result in the discovery of a leak, it is concluded that the leak is too small to bother with, which may not be the case. It is the author's contention, based on his associates' 40 years of field experience, that the intensity of sound does not necessarily indicate the volume or size of a leak.

An actual measurement of the flow between a set of valves when use is at a minimum, or is a known quantity, is a *positive* approach. Only after a water measurement is made can it positively be said that leakage does or does not exist, and, if there is leakage, only by a water measurement can the amount be determined. In the pitometer survey it is at this point that sound intensifiers are first used. Then with a definite knowledge of the size and approximate location of the loss, investigations are made with whatever type intensifier the engineer prefers, until all leakage of sufficient importance to warrant repair is located.

The record is full of instances where the sound indications were so misleading or faint that large leaks had existed for years and would never have been found if there had not been a definite water measurement to go by and to force the engineer to continue his investigation until a remeasurement showed that all the leakage in the section had been repaired. Take, for example, interfering noises from pumps, motors, regulating valves, machinery, etc., or the case of a deep fill, a river-crossing or an abandoned service.

In this connection it is worth noting that the quantity of leakage located, rather than the number of leaks, is the important consideration to a community. For example, a survey was made in a metered New England city having a domestic per capita consumption to 64 gpd. Only a handful of small service leaks were found in the distribution system proper, but because the survey was a complete audit, a measurement was made on a pump-

ing line leading to a reservoir some distance out of the city. This main crossed some rough and swampy ground and there were no connections to it. The function of the pump station was to augment the main gravity supply to the reservoir and whenever the water level dropped to a certain point the pump started and ran until the reservoir was filled. The measurement on this main showed a loss between the pump station and reservoir of 430,000 gpd. and further investigation resulted in the discovery of a leak wasting 250,000 gpd. into the swamp, when the pump was off, and 390,000 gpd. when it was operating and the pressure thus increased. This one leak was largely responsible for the need of pumping, as it was continuously draining the reservoir. The savings in pumping costs alone amounted to $4.50 per day at one cent per kilowatt hour. Thus this community, with an exceptionally tight distribution system, was able to make a very substantial saving in its operating costs.

At the other extreme, is the case of a large unmetered gravity system where leakage and waste were rampant because there was an abundant supply. Unfortunately the capacity of the 7-mi. transmission mains was limited and shortly before the war the demand had increased to the point where pressure troubles developed and it was necessary to curtail service in order to get water into the large distribution reservoir. Then with the war came a large arsenal that demanded 10 per cent of the total consumption. This additional amount could not be supplied and so the government authorized a complete pitometer survey as the quickest and most economical approach to obtaining an additional supply. Here the resultant action could be called selective leak location. Only the large leaks were dug up and repaired at first so as to reduce consumption as rapidly as possible, and in this case measurements were invaluable. Hydrant leaks making a terrific roar were encountered on almost every other corner, and yet broken mains, part of the time submerged by the tidal river, made no noise at all on the surface of the street due to the nature of the ground conditions and undermined pavements. Within six weeks, leaks releasing over 4 mgd. had been repaired and at the completion of the survey leaks totaling 13 mgd. had been located.

In addition to providing positive information regarding leakage, the night subdivision measurements have several other valuable features. During the course of the measurements, it is necessary to close a large majority of the valves in the distribution system and prove their condition by making tight shut-outs. Periodic inspections and operation of all valves in a distribution system is generally considered good practice. Usually, however, shut-outs are not made during the inspection, the main object being to see that the valve is free and in good condition. When a survey is made the night valve operations can take the place of the annual inspections. Many systems do not follow a valve maintenance program at all and in these cases the operations made during the survey are useful, not only as a check on the condition of the valves, but also on the distribution system map and records. One of the most interesting discoveries resulting from valve operations occurred in a southern city where it was found that a great many of the mains were not connected at intersections. This, it was said, came about as a result of

street grading after part of the system had been installed, thus increasing the cover. When the gridiron was completed, no effort was made to connect mains that were at different depths. Only by methodically proving how the water was circulating were all these missing connections located, and the improvements in the strength of the distribution system after connections were made can be readily appreciated.

House Waste

The only sure way to eliminate unnecessary waste on the consumer's property is by universal metering. There are, however, many communities where universal metering is impractical for financial or political reasons, and in these communities only the largest consumers are metered.

The only other method of controlling this waste is by periodic house-to-house inspections and these are most efficiently supervised when the amount of water being wasted is first determined by night measurements. Following these, concentrated work in those sections found to have a large night consumption will produce the best results.

The benefits from these inspections are only temporary unless repeated at regular intervals and even then have no control over willful waste. However, a pitometer survey will indicate the most wasteful sections and several cities have adopted ordinances authorizing the water department to install meters when reinspections show that the consumer is a chronic waster of water and will not keep his fixtures in repair.

Distribution Studies

A second type of survey, the distribution study, has been discussed elsewhere recently by the author. He has shown the value and method of determining the true physical condition of a distribution system before designing improvements. While the object of these studies is somewhat different from the waste survey, the basic data accumulated through loss-of-head tests, fire flow tests, pressure and hydraulic grade line studies and computations are all dependent on a variety of flow measurements and gagings.

Whether the problem be the location of points of waste or the proper method of extending or improving the distribution system, the pitometer survey will be found to be a most valuable method of finding the proper solution.

Uprating Distribution Systems by Cleaning and Cement Lining

By J. A. Frank

Engr., National Water Main Cleaning Co., New York, N.Y.

Presented on Nov. 3, 1944, at the New Jersey Section Meeting, Atlantic City, N.J.

BECAUSE wartime restrictions on men and material make the laying of new mains extremely difficult, the rehabilitation of distribution systems by cleaning and lining is being practiced as the least expensive and quickest method of obtaining additional capacity.

There are many modern practices in both cleaning and cement lining and, with proper scheduling, the work can be done much more quickly than it would be possible to lay new pipe.

Modern Practices

The cutting of cast-iron pipe has long been a laborious, tricky and uncertain job and there is a decided trend toward the use of machines for this work. In smaller pipe the use of a wheel-type cutter has been standard practice but, unfortunately, it cannot be used with any degree of satisfaction in sizes over 10 in. There are a number of methods which have come into use in the last few years for cutting the larger sizes of cast-iron pipe. The first of these methods utilizes a split machine which is clamped around the pipe. One or more tool bits of the parting-tool type travel around the pipe, cutting the metal with a straight even cut.

The second device consists of a pipe-cutting machine which travels around the pipe on a track of chain. The power unit, which is either an air or an electric motor, is connected through a gear box to a rotary saw which travels around the pipe, removing the metal with a straight even cut.

The third method utilizes the electric arc-welding machine, which produces good cutting results by the use of a negative polarity rod in straight polarity. It is necessary to have a high output machine and a special technic is required of the welder handling the electrode. Under proper conditions this method can be very rapid and result in an even true cut.

The development and utilization of these three methods of cutting have resulted in speeding up the work of cleaning, and the even cuts made possible by them permit the use of the nipples taken out of the pipe, thus reducing costs for material on the job.

The installation of the cleaning tool into either the nipple cut or the pipe in the ground long had been a laborious and time-consuming job. In recent years methods have been developed for inserting the cleaning tool so that it now takes only a few minutes.

Present day pipeline fittings serve as another means of speeding up cleaning. By the use of mechanical-type couplings, such as Dresser, Skinner or Simplex, coupling up of the pipe after

the cleaning machine has been inserted now requires only a few minutes, as compared with the practice of yesteryear which sometimes consumed hours.

Another factor in speeding up the cleaning process has been the accumulation and compilation of data on the required flow and pressure to propel the machine for cleaning. It is now possible to predict with reasonable certainty what pressures and quantities are going to be required to propel the machine and the approximate speed at which it will travel. With this knowledge, the work can be scheduled and laid out so that many former uncertainties no longer exist.

One of the most recent developments in connection with water main cleaning is the use of two-way radios for communicating from point to point and

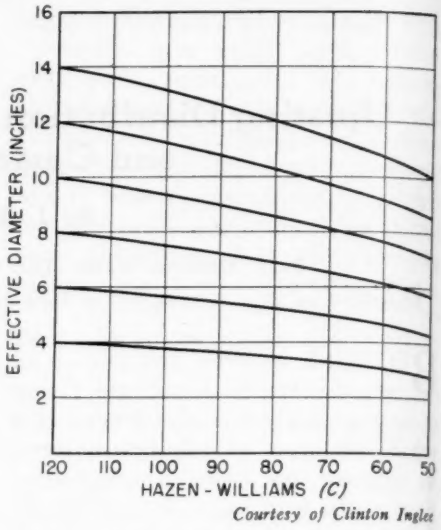

FIG. 2. Graph Showing Effect of Roughness of Pipe Interior on Carrying Capacity —Pipe Sizes 4 to 14 in. in Diameter

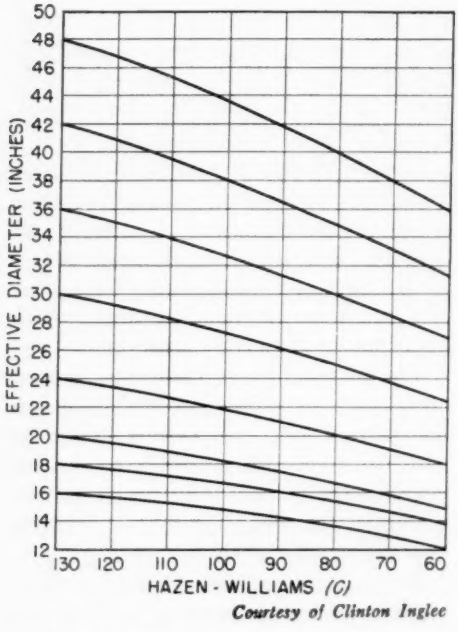

FIG. 1. Graph Showing Effect of Roughness of Pipe Interior on Carrying Capacity —Pipe Sizes 16 to 48 in. in Diameter

controlling the job. In the cleaning of large mains in distribution systems, we are faced with the problem of the disposal of large quantities of water in heavily populated districts. The use of the two-way radio insures shut-offs before any damage can be done in the event of any failure of facilities to carry off the water.

Figures 1 and 2 show two sets of curves which illustrate the effect of the roughness of pipe interior on carrying capacity. Some average coefficient for new pipe had to be assumed and in these curves the Hazen-Williams *C* value of 130 has been assumed for pipe 16 to 48 in. in diameter, and 120 for smaller diameters.

Figure 1 covers pipe in the sizes from 16 to 48 in. To read the uprating of a pipeline by cleaning, note that a 48-in. line with a coefficient of 115 has an effective diameter of 46 in. In this size pipe, cleaning would restore the

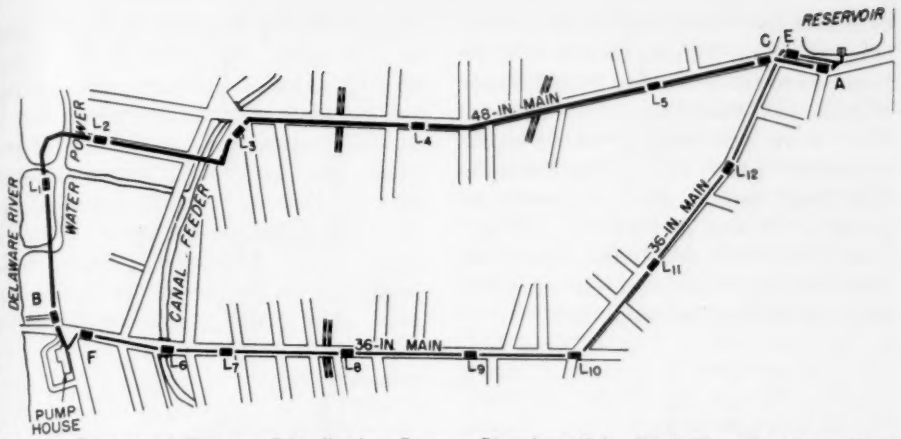

FIG. 3. Layout of Trenton Distribution System Showing 48-in. Lock-Bar and 36-in. Cast-Iron Bell-and-Spigot Ascending Mains

main to 130 and the effective diameter would be increased to 48 in.

Figure 2 covers pipe from 4 to 14 in. in diameter. A 14-in. pipe with coefficient of 80 would have an effective diameter of 12 in. By cleaning, this can be increased to 14 in.

As an example of successful restoration of an old line to satisfactory carrying capacity, a record of operation in Trenton, N.J., will be of value.

Main Rehabilitation in New Jersey

Water for the city of Trenton is obtained from the Delaware River. An intake, built out into the river, supplies water to the suction side of low-lift pumps, whence it is pumped to the filter plant and there treated. The treated water flows by gravity to the suction side of high-lift pumps and is then carried through two ascending mains to the service reservoir which has a capacity of approximately 60 mil. gal. One ascending main is a 48-in. lock-bar laid in 1907. The other is a 36-in. cast-iron bell-and-spigot laid in 1870. Figure 3 shows the plan of lines.

During the summer of 1940 it was decided to appraise these lines, determine their condition and lay out a suitable plan to insure their life. Since the lock-bar line was made of plate only $\frac{5}{16}$ in. thick and, because access manholes were available, it was decided that this should be inspected first. Accordingly the line was shut off and dewatered. A manhole cover was removed and an access plate taken off so that it was possible to enter the main and inspect it. It was found that the line was in remarkably good condition for its length of service. Very little tuberculation and no incrustation were present. The original coating had been an excellent job but, in numerous places, it was completely gone and the bare steel was exposed. At the points where the steel was exposed, evidences of deterioration could be seen. After inspection the access plate was bolted up and the line restored to service.

Since the 36-in. ascending main had no access openings, inspection would have been extremely expensive. Therefore, tests were made on Aug. 29, 1940, to determine the coefficient of each line. The 48-in. lock-bar was found to have a coefficient of 108. The 36-in.

cast-iron line was found to have a coefficient of 66. During the fall of 1940, plans were made for the rehabilitation of these two lines and in the spring of 1941 work was started which would eventually result in cement lining of both these lines *in situ* by a centrifugal process. It was decided to clean and cement-line the 48-in. line first and, after this was back in service, to clean and cement-line the 36-in. line.

simple. Using the plate of the air vent as a template, the welder cuts around all four sides of the plate after having set the plate so that its center line is on the vertical axis at the top of the pipe. The plate cut out is then removed and the hole in the pipe trimmed up. Then the frame for the vent is centered up over this hole and a heavy bead placed all around the frame on the outside. The gasket is then installed, the

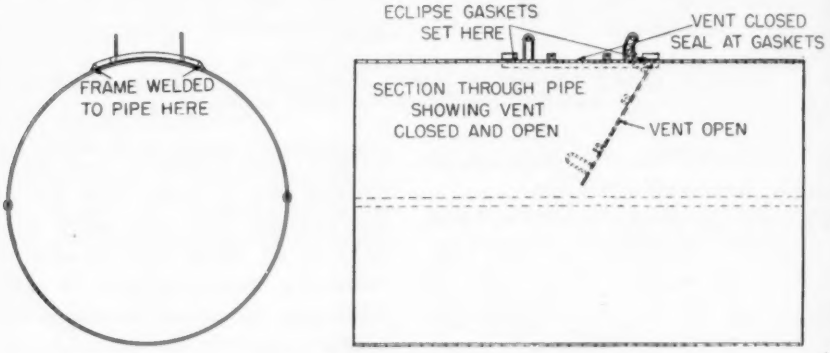

FIG. 4. Air Vent Attached to Pipe

Cleaning a 48-in. Line

In cleaning a steel line of this size there are a number of factors which must be considered and planning and scheduling must anticipate these problems.

Because of surges which may occur during cleaning, with resulting negative pressures, it is imperative that air vents capable of handling large quantities of air be installed. These air vents, or vacuum breakers, preclude the possibility of collapsing the pipe when, for any reason, a vacuum occurs in the line. Figure 4 shows the air vents which were designed and installed for this purpose.

As can be seen in the figure, the installation of such an air vent is rather

plate part of the vent lowered into the pipe and wedged up until ready for use.

The cleaning of the 48-in. lock-bar entailed the installation of two such vents; one in the nipple where the machine was introduced and the other at a point where access was had to determine whether or not there were stays in the line.

The vents gave two orifices at high points in the line, rectangular in cross-section, 18 × 24 in., through which air could enter the line (if the pressure inside the line became lower than atmosphere), and obviated all danger of collapsing the pipe.

Another danger in cleaning a line of this size is in allowing the machine to come out of the pipe, particularly on a down-hill shot. This danger obtains

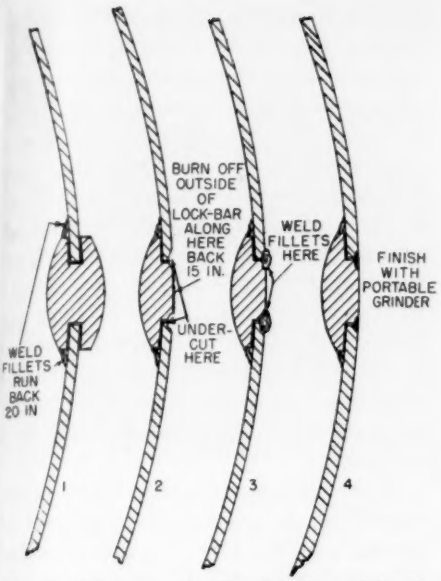

FIG. 5. Steps in the Preparation of Lock-Bar Pipe for Dresser Couplings

because of the piston effect of the machine. Should it be allowed to emerge completely, the sudden drop in water pressure in the line could conceivably cause the pipe to collapse. There is also the danger of spilling the tremendous quantities of water through the unobstructed pipe. To prevent this, it was necessary to build a very strong bulkhead in the hole where the machine was to make its exit, so that only part of the machine should leave the pipe and the piston-like skirt remain in the main, the water thereby draining out comparatively slowly. Plans for the bulkheads were made before the work started.

One of the problems to be considered in this job was the coupling up of lock-bar pipe. It was decided to use Dresser couplings for coupling up the nipples cut out for the entrance and exit of the cleaning and lining machines. Figure 5 shows the steps in the preparation of the pipe.

To prepare the pipe for the use of Dresser couplings it was necessary to cut off the outside of the lock-bar. The method used was to run two electric arc fillets along the inside joint of the lock-bars, both top and bottom, for a distance of 20 in. at both ends of the nipple. The lock-bar was then undercut on the outside, as shown in Fig. 5, and a fillet thrown on the outside which was finished off with a portable grinder, thus presenting a smooth surface on which the gaskets of the Dresser couplings could make a good seal. As can be seen from Fig. 5, the electric arc weld on the inside runs back for 20 in. and the cut of the lock-bar on the outside extends only 15 in. This overlap obviated any danger of a leak at this point. The lock-bars on the pipe projecting into the hole in the ground were treated in the same way except that the fillet on the inside was extended back only 12 in. and the cut on the outside 8 in. The Dresser couplings used had a width of 15 in. so that by placing the couplings on the nipple and dropping the nipple into place, then sliding the couplings over the pipe projecting into the hole, it was possible to center the Dresser sleeves over the cuts in the pipe.

An important step in planning such work is the selection of entrance and exit points for the cleaning machine. The exit point is particularly important because here it will be necessary to dispose of large quantities of water. After a careful study the points were selected and the planning phase of the job was completed.

Work was started on June 2, 1941. Three excavations were made for the cleaning, which involved shooting a cleaning tool by water pressure from the reservoir back to the pump station. An excavation, as close to the reservoir

as possible without undue interference with the fittings, valves, etc., was made on the 48-in. line. This excavation was 12 ft. long, 8 ft. wide and 10 ft. deep, which left 2 ft. of working room all around and under the pipe. In Fig. 3 this excavation is shown at (A) on the plan. So that the large quantity of water discharged during cleaning could best be handled and emptied into the Delaware River, the exit excavation was made 100 ft. back from the gate at the pump house. This excavation was made at (B) on the plan. It was 12 ft. long, 8 ft. wide and approximately 10 ft. deep. The 2 ft. of working room around the pipe, which had been the objective, was interfered with in two places. At one point an 8-in. service main running from the pump house to the filter plant projected into the hole; on the other side a 60-in. concrete sewer cut down on the working room. This hole was "tight-sheeted" using 3×10 tongue and groove sheeting. On the side of the excavation nearest the river, the sheeting was cut low and a flume fitted into the notch thus made. A flume, 50 in. wide, 25 in. high and approximately 250 ft. long, was constructed to convey the water overflowing through the notch in the sheeting into the Delaware River. Every effort was made to see that all preliminary work was completed before taking the line out of service so that the length of time the water was pumped through a single line—and the consequent higher pumping costs—would be held to a minimum.

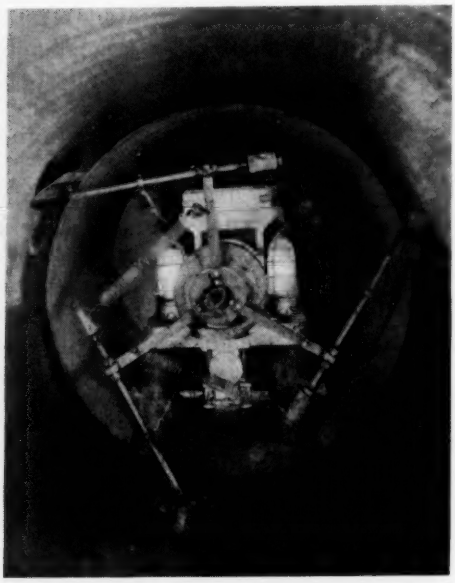

FIG. 6. Lining Machine for 36-in. Main

After all preparation had been made, the 48-in. lock-bar was taken out of service on June 11. The line was shut off and the air valves checked to make sure they were in working order. A blowoff at a low point was opened and the line dewatered slowly to avoid the danger of pulling a vacuum and collapsing this steel pipe. The dewatering process took from noon on June 11 until 8:00 A.M. on June 12.

Using the oxyacetylene torch, a nipple 6 ft. 6 in. long was cut out of the 48-in. pipe at (A). Actually three cuts were made as 1 in. was cut off the nipple so that it could be easily put back into the main by using Dresser couplings. The nipple was lifted out of the ditch so that an automatic air vent could be installed; the cleaning tool was then jacked into the nipple and the lock-bar prepared for Dresser couplings.

A nipple was cut out at the exit hole and a bulkhead built which prevented the complete emergence of the machine. The nipple, with the machine in it, was dropped into place in the line and coupled up with Dresser couplings.

Through the co-operation of the Trenton police it was possible to secure

FIG. 7. View of 36-in. Main Before Cleaning, Showing Severe Tuberculation

the services of two two-way radio cars to facilitate the control operations. This was accomplished by leaving one radio car at the control valve so that the operator could immediately relay any instructions to the valve crew. The other radio car was used in following the machine so that it was possible at all times to increase or decrease the flow behind the machine.

When all was in readiness, the valve was slowly opened behind the machine until the pressure reached approximately 8 lb. The machine started off and proceeded at a slow rate through the pipe. The last 2,000 ft. of this line have a very sharp down-grade. As soon as the top of the grade was reached, the large quantity of water contained in the 5,000 ft. of pipe behind the machine was converted into head and, as the pressure increased, the speed of the machine increased so that its travel through the last 1,500 ft. was very rapid. During the shot it was found that with a pressure of approximately 8 lb. behind the machine, water at a 22-mgd. rate was consumed.

An inspection of the pipeline after this shot showed that, at the beginning of the line where the progress of the machine had been slow, the cleaning was a thorough job, but that the last 1,500 ft. of the shot had not given a very good cleaning job due to the rapidity with which the machine had traveled through this section of pipe. It was decided to shoot the machine again to see if it would be possible, by shutting off the water before the down-grade was reached, to control the speed of the machine so that a more thorough job of cleaning could be accomplished. This was attempted on June 20, but it was impossible to hold down the speed of the machine to a desirable point.

It was then decided to shoot the machine uphill, that is, from hole (B) (in Fig. 3) toward hole (A), using the pumps at the pump station as a source of pressure. This necessitated the "tight-sheeting" of the hole at (A) and the building of a rugged bulkhead at this point so that the machine would not come all the way out of the pipe with a resulting surge of water.

The fact that the point where the wash water was to be disposed of was in a rather heavily populated district presented another problem in shooting uphill. It was necessary, therefore, to make a survey of the sewer system in the area to determine how to dispose of the large quantity of water which would be discharged during the shot. The problem was solved by sand-bagging along the curbs of the streets and distributing the load over a number of large storm sewers. When all of the preparatory work was completed the machine was shot uphill and, in this process, it was possible to control its speed very accurately, using the radio cars as a means of communication with the pump house.

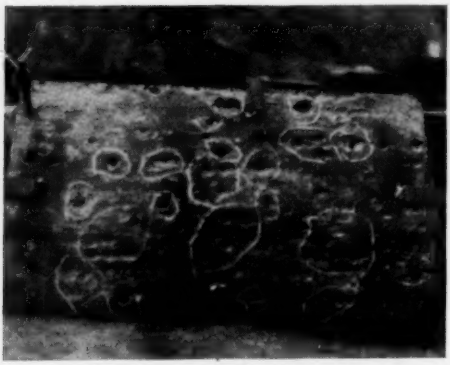

FIG. 8. Corrosion and Pitting Discovered on Portion of 36-in. Main Before Lining

After this uphill shot the line was found to be properly cleaned and was ready for the cement lining.

Lining a 48-in. Line

The 48-in. cement-lining machine is powered by an electric motor and travels through the pipe, applying the mortar centrifugally as it travels. It is followed by adjustable rotary trowels. Current for the motor is supplied through a cable which is run inside the pipe back to a mobile alternator. As the lining machine travels back through the pipe, the cable is pulled toward the alternator and wound up on a reel.

The cement mortar is mixed in a mobile wet batching machine. The mortar is dropped through the chute at the hopper and into rubber-tired buggies placed below it inside the pipe. The buggy, full of mortar, is pushed to the lining machine, the mortar transferred to the hopper of the lining machine and the buggy returned for another load of mortar.

Figure 3 shows how the lining machine was inserted in the pipe at the hole near the filter plant and run back toward the pump station. The batching machine and the alternator were located at this hole and the pipe was lined from the gate at the pump house back to the hole. The batcher and the alternator were moved to the first access hole, the nipple dropped into place, coupled up and the machine placed the lining right through the nipple.

Because of the mortar transportation problem it was necessary to have small holes about every 1,000 ft. so that the wet-mix concrete could be dumped through a chute into buggies at these points and transported for shorter distances to the lining machine itself. It will be seen on the plan that there were a number of small excavations where this was done. After the lining was completed, the manholes were bolted back and the lining was made one continuous cylinder right past these access manholes.

When the exit hole at the far end was reached, the machine was turned around and sent up into the pipe at the far end. The pipe was lined back to the hole, the lining machine lifted out of the hole, the nipple lined up on the ground, lowered into place and coupled up. Thus a continuous lining was provided from one end of the pipe to the other.

The line was sterilized and put back in service on July 31. The sterilization was accomplished by feeding water containing chlorine to the extent of 60 ppm. and running it right through into the reservoir. Although this water as it entered the reservoir had a very high residual, there never was detected any increase in residual in the distribution system.

With the 48-in. line back in service —it had been out of service only 38 working days—it was now possible to go ahead with the cleaning and cement lining of the 36-in. line.

FIG. 9. Portion of 36-in. Main After Cleaning and Before Cement Lining

Cleaning and Lining a 36-in. Line

The 36-in. line was laid in 1870 and there was no record of some of the older connections to it. This line was shut off on Aug. 1, 1941, and, with the 36-in. line off, a test was run on the 48-in. line for leakage. We were unable to measure any leakage in this line after cleaning and cement lining although the test was run over a 24-hour period.

On August 2 the 36-in. line was dewatered by running the water out through a 16-in. side connection. An attempt was made to cut the cast-iron pipe by means of the electric arc at the point (E) which was to be the entrance hole for the cleaning machine. The attempt was not successful because it was impossible to obtain an electric arc welder having a capacity larger than 200 amp. and, for the successful cutting of this thickness of cast-iron, a machine of at least 600-amp. capacity is required. This nipple was finally cut out using an oxyacetylene cutting torch of special design and the results obtained with this method of cutting were very good, as were the results of the cutting at the exit hole (F). However, this exit hole presented an excavation problem. So that there would be ample working room around the pipe, it was necessary to drill out with an air drill some very tough granite known as the "Trenton streak." There was some delay because of this but the excavation and "sheeting" of the hole was completed on August 5.

The 36-in. cleaning machine was placed in the nipple which had been cut at (E) in Fig. 3 and, on the night of August 5, when everything was in readiness, the shot was made.

In the course of this shot the machine negotiated two short-radius 90-deg. bends. Examination of the pipe showed that a very good job of cleaning had been done but that an additional shot would be necessary to attain the smooth condition needed for a good cement lining job. During this shot the radio police cars were again used.

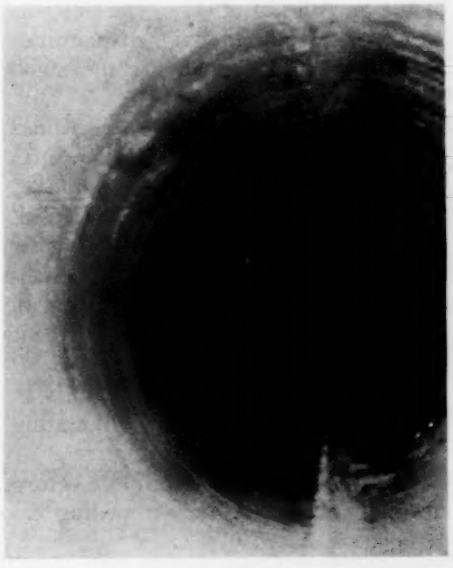

FIG. 10. 48-in. Lock-Bar After Cleaning and Cement Lining

It will be noted that the hole (F), where the machine emerged, was located in the middle of a main highway, which is a main thoroughfare from New York to Philadelphia. Due to the large quantity of water discharged on the street, traffic was diverted around this block for two hours during the time the shot was made. A second shot was made during the night of August 6 and examination of the pipe after this shot showed that an excellent job of cleaning had been done and that the pipe was ready for cement lining.

Figure 6 is the 36-in. lining machine.

Access for cement lining was had at a number of points indicated on the plan (Fig. 3), and manholes were fabricated by drilling a series of holes making a circular piece which could be broken out of the top of the pipe. A saddle was then fastened to the pipe and a cast-iron plate fastened in this saddle. No particular difficulties were experienced during the lining of the 36-in. pipe and the work was completed on Aug. 21, 1941. The line was sterilized, using the same quantities and procedure outlined for the sterilization of the 48-in. line.

A test was made on these two lines more than two years later, on Nov. 10, 1943. The 48-in. line was found to have a coefficient of 144 and the 36-in. of 135, as compared with 108 and 66 before rehabilitation. These coefficients are corrected for the reduction in area due to the thickness of the cement lining.

The reduced friction loss results in considerable power saving amounting to from 15 to 17 per cent.

Figure 7 shows the 36-in. line before cleaning. Note the flow-impeding tuberculation.

Figure 8 shows the condition of a portion of the steel main discovered during the lining process. It can readily be seen that the corroded and pitted condition was serious and would soon have led to trouble.

Figure 9 shows the same pipe after cleaning and ready for cement lining.

Figure 10 is a view of the 48-in. lock-bar with its lining. The lining is so smooth that it reflects back the light and gives a wavy appearance in the photograph.

Another result of the cement lining is that the 48-in. line has been made bottle tight. In the five-year period preceding the cement lining of these two mains, leakages—bad enough to need repair—were found on the average of eight times per year. Since the completion of this work in 1941 not one leak has been discovered on the 48-in. line. In addition, a leakage test run on the 48-in. and 36-in. lines together showed a leakage so small that it is practically impossible to measure it.

The job has been of great benefit since costly repairs which would have been necessary have been obviated; the two lines are bottle tight; and the friction loss has been reduced so that pumping costs are held to the value for new pipe.

Acknowledgments

The author wishes to express his appreciation to Alvin Bugbee, Supt. and Chief Engr. of the Trenton Water Dept., and his staff for their cheerful co-operation in supplying data for this paper. The author is also indebted to H. Seaver Jones, Pres. of Centriline Corp., and members of his organization for their help in preparing this article.

Getting Designed Capacity From Distribution Systems by Cleaning and Lining

By David Auld

Asst. Supt., Water Div., Washington, D.C.

Presented on Nov. 10, 1944, at the Four States Section Meeting, Philadelphia, Pa.

SECURING improved capacity within the water distribution system of the District of Columbia has been a matter of deep interest to the water department for some years. The system contains some major trunk lines which were placed in use prior to 1860 and the backbone of the most critical of the various service areas has an average age of about 50 years. All of these early mains are of cast iron and have carried filtered water since the year 1905. Prior to that time only settled water was available to the city. Since lines of this type are subject to a continuous decrease in capacity, their usefulness is constantly being reduced. Simultaneously with the steady growth in consumption, of course, the demands on these same lines have increased. A report of the New England Water Works Association's Committee on Pipe Line Friction Coefficients, published in 1936 (1), showed that the average actual loss in the capacity of tar-coated cast-iron pipe of various sizes after 30 years of service was 52 per cent. The tests on which this finding was predicated covered 473 pipelines in nineteen different systems. The general experience in many cities investigated showed that the actual loss in capacity was greater than the 32.3-per cent average predicted in the Hazen-Williams tables for a like period.

The historical cost of the thousand-odd miles of filtered water transmission and distribution mains in the Washington system is approximately $20,000,000. Based on today's costs, perhaps as much as $33,000,000 would be required to duplicate these same lines. To the extent that their capacities are reduced through corrosion, it can be considered that the investment represented by these lines is being correspondingly dissipated.

Recognition of these facts prompted the present policy in Washington, under which all new lines are constructed so as not to be susceptible to appreciable loss in capacity, and old lines essential for efficient distribution are being systematically rehabilitated so as to restore and, where practicable, maintain their capacities. All trunk mains constructed in the past ten years have been of lined ferrous pipe or reinforced concrete. Linings for steel mains have been of tar-base enamel. Linings for cast-iron mains have been of cement. All grid mains, which have been laid recently, are also cement lined. The District distribution system now contains about 30 mi. of lined trunk mains of 30-in. or larger diameter, and about 35 mi. of cast-iron trunk mains within this same size range, the greater part of which will ultimately be lined in place.

The program for cleaning and lining received considerable impetus as a result of suddenly increased water demands from a rapidly expanding population. While the system as a whole was remarkably free from serious trouble, acute conditions did develop in one locality. This area is separated from the rest of the city by the Anacostia River and, because of its remote location, was largely undeveloped. It provided the most readily available land for new housing, as well as new army and navy establishments.

The water supply to this territory is drawn through the heart of the congested business and government office district, which contains most of the older pipelines in the whole system. After crossing the river a part of the water reaches consumers by a continuation of gravity flow and the rest is pumped to two higher services. Since 1940 the average consumptions have more than doubled and peak demands have, on occasion, been three times prewar levels. Within the area itself some new trunk line construction was unavoidable. However, this alone could not solve the entire problem. During periods of high demand, pressures available to the suction side of the high-service pumps were so low that their output fell well below capacity.

In order to improve the pressures here and also to get more water into the area, it was decided to clean and line about a mile of 36-in. diameter, cast-iron trunk main, which was one of the several principal feeds. Flow tests made on this and other critical mains showed them to be in particularly bad condition. The main being rehabilitated was laid in 1904. The Hazen-Williams coefficient was about 70. Another trunk, 24 in. in diameter, also feeding this area, was shown to have a coefficient of less than 50. This line was built in 1891, and it was decided to clean it also. Both were of cast iron.

Planning Operations

The limits of the work selected should, where possible, be governed by need. It is probable, however, that a limitation of funds or the situation of the main within the system may be such that something less than the ideal must suffice, insofar as any individual project is concerned. While the operation requires relatively little time as compared with new construction of equal benefit, it must be possible to provide a continuous adequate supply through other mains in the system during the rehabilitation period. In Washington other mains took over the load and water from the next higher service area was bled into one of these lines part of the time. If domestic service connections should be supplied from the trunk, they could best be fed from a temporary line laid above ground. Where local grid mains would go without supply, temporary lines linking otherwise isolated areas can be laid along the surface. The performance of the work during periods of low consumption will, in general, be safer and more convenient.

A thorough study of the main to be lined will indicate certain obvious places where cuts will be required. Valves, for example, are not infrequently one size smaller than the mains and such obstructions will not permit passage of the cleaning machine. Ordinary bends and tees do not necessitate the making of special cuts.

The lining of an old main provides an excellent opportunity to study the location and usefulness of existing valves. It is likely that the gradual

addition of other trunks, perhaps connecting to the main line, may have outmoded the existing valve arrangement. It was found in Washington that some valves could be permanently removed and others relocated to more advantageous positions without appreciable extra cost or inconvenience, since openings in the 36-in. main were necessary in any event.

While the flow of water for hydraulic cleaning can be accurately controlled, it is, nevertheless, essential to provide an adequate means of disposal. A check of the capacities of all sewers receiving these flows is an essential precaution in closely built-up areas.

In addition to the hydraulic cleaning it is likely that a limited amount of hand cleaning will be required in the short sections of pipe, between the pipe opening and the valve "upstream." Such stretches, from 10 to 50 ft. long, cannot, of course, be reached by the cleaning machine. Such stretches exist when underground obstructions, surface improvements or traffic conditions prevent the pipe cut from being made as close to the end of the work as desired.

The cement lining used in Washington was applied by a machine probably familiar to most water works engineers (2, 3). The machine, which is a self-propelled type, projects the lining mortar against the pipe by centrifugal force imparted by a rapidly revolving head which is supplied by a screw feed, and trowels the lining surface mechanically. The mortar was applied in a $\frac{3}{16}$-in. thickness. Provision was made for an increase in thickness in case the condition of the main warranted it. All pipes and appurtenances connecting with the main to be lined were plugged or otherwise protected by the contractor who hand-pointed these openings when the lining had set sufficiently to permit entry into the pipe. At the end of every day's work the completed section was closed at each end to prevent circulation of air. Water was then introduced between bulkheads to promote proper curing. Sections between gate valves were filled with water as soon as possible. The main was thoroughly sterilized before its return to service.

The labor for excavations, pipe cuts, the handling of flushing water, valve operation and final cleaning up, including repairs to pavements, was furnished by the District. All equipment for cleaning and lining, as well as the labor required for the latter, was furnished by the contractor.

Results

Careful measurements of the flows and losses showed that after lining the 36-in. main had a coefficient in excess of 140, based on nominal diameter—twice that obtaining in portions of the line before work was started. The 24-in. line, which was cleaned but not lined, showed a coefficient of 121, which was an increase of more than 50 per cent. Translated into terms of usefulness, these mains are capable of carrying about twice as much water as formerly, with the same loss of head. The main which was lined may be expected to retain a capacity which closely approaches that which it had when laid in 1904.

Although the work described involved only a very small part of the total length of the lines supplying the critical area, the improvement was distinct. After cleaning and lining, the pressures available to the suction side of the high-service pumps at no time fell below 20 psi., whereas formerly they frequently fell to 15 psi. This im-

provement can be attributed entirely to the cleaning and lining operation. The 5-lb. increase in suction pressure, while apparently small, served to increase the discharge of the largest pumping unit by 33 per cent. The benefit can be more fully appreciated when it is realized that consumptions in this area were about 20 per cent greater during the summer of 1944 than during the previous summer and, notwithstanding this greater load, the pressures were consistently better than formerly.

Cleaning a 20-in. Main

In addition to rehabilitating the trunks supplying the area across the Anacostia River, it suddenly became necessary to provide immediate relief to a section within this area. During the summer of 1943 certain localities were without water during hours of high demand. The only feed was a 20-in. cast-iron main, most of which was laid in 1911, having a coefficient of from 62 to 68. During the spring of 1944 this line, over 3 mi. long, was hydraulically cleaned, with a resulting coefficient of 123. During the summer of 1944, notwithstanding the completion of numerous war housing projects in the locality since the previous summer, no low-pressure complaints were received from consumers.

The cleaning of the 20-in. trunk presented more difficulties than did either of the other lines. There was no alternate feed into the territory served except from the next lower and next higher services, which had to be temporarily rearranged. Numerous customers' premises were also connected directly to this line. In view of the short time required for cleaning only, it was decided to perform the work without provision of temporary local service. All premises to be affected within the limits of a section to be cleaned were notified of the hour of water shut-off by circulars delivered to their doors. The preparations for pipe cuts were made during daylight and the actual cuts, with subsequent cleaning, were made at night. The pipe was then immediately reconnected and charged and chlorine solution added to produce a residual of over 100 ppm. The circulars delivered to the consumers had advised that when water was restored it must not be used for drinking or cooking except after boiling for 5 min. so as to drive off the excess chlorine. By this arrangement there resulted little general inconvenience to the public because, except during a single night, all house plumbing was available. Samples of the water in the recharged main were immediately taken to the laboratory and, if tests were satisfactory after 48 hours, the special chlorination was discontinued. When conditions in the cleaned main were considered to be entirely safe, the customers were again served with written notice that no further precautions were necessary. At one school house affected by the work, the water department provided a tank wagon with faucets from which children could secure drinking water. All drinking fountains in the school building were turned off.

Expenses Involved

The cost of the work was modest when considered in the light of the benefit obtained. Cleaning and lining of the 36-in. main cost a total of $3.92 per lin.ft. The contract cost was $3.20 per ft. Materials furnished by the District, including sleeve-type couplings, bracing and sand bags, cost $0.22 per ft., and labor, equipment and paving repairs cost an average of $0.50 per ft.

For the cleaning only of the 24-in. line, the contract cost was $0.11 per ft., materials supplied by the District cost $0.04 per ft. and District labor, etc., amounted to $0.175 per ft. for a total of $0.325. For cleaning of the 20-in. line, the contract cost was $0.11 per ft., materials $0.024 per ft. and labor, etc., $0.448 per ft., making a total unit cost of $0.582. The latter cost reflects the difficulties previously recounted. These costs are in line with the cost of similar work elsewhere.

Advantages of Cleaning and Lining

It is unfortunate that the art of lining water mains in place does not yet cover the entire pipe size range found in distribution systems. The method employed in Washington is now perfected for 36-in. and larger diameters and may soon be available for 30-in. diameter pipe. Among the larger sizes, the hand application of tar-base enamel lining has been effective in improving capacity (3, 4). Another method of lining with cement mains of from 4 to about 12 in. in diameter in place is also in successful use. There are numerous accounts of this process in past issues of the JOURNAL and other publications (5, 6, 7, 8). Since it is in the smaller sizes that the greatest relative loss of capacity occurs, this method can be an invaluable aid in restoring high coefficients both quickly and cheaply. Published costs of such work in Charleston, S.C., during 1939 showed that the cleaning and lining of 8-in. mains cost from $0.50 to $1.55 per ft., depending on the type of street paving and the number of service connections encountered. Six-inch lining varied from $0.46 to $0.90 for similar conditions. *C* values obtained were approximately 130, based on nominal pipe diameters. More recent work of this sort in San Diego showed somewhat greater costs but equally satisfactory results.

The method of attack employed in improving a situation which was jeopardizing a District area of about 7,000 acres, with a population of 125,000 persons, most of whom were engaged in some activity supporting the war effort, was fully justified by the results. The carrying capacities of critical mains were restored in several months, with an expenditure of a negligible quantity of materials, few of which were of a critical nature. Comparable relief from new construction would have cost many times more in both time and money. The benefit of lining may be considered as permanent and will be enjoyed long after war demands have ceased.

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A Photometric Method for the Determination of Nitrates in Water

By H. H. Wittenberg and G. K. Crowell

Div. of Chemistry and Sanitation, New Hampshire State Dept. of Health, Concord, N.H.

A Contribution

THE photometric method for the determination of nitrates in water utilizes, with a few modifications, the phenoldisulfonic acid reaction as outlined in the *Standard Methods of Water Analysis* (1).

In the pertinent literature, there are few references to photometric methods for this determination. Trofimov (2) outlines a photometric procedure utilizing the diphenylamine reaction. Stoll (3), in a report of his photometric study of nitrogen compounds in sea water, states that the method involving Harvey's reagent is not altogether reliable in the presence of considerable tri-valent iron and tetra-valent manganese. A pamphlet issued by the Central Scientific Co. of Chicago (4) gives in detail a photometric procedure using the phenoldisulfonic acid method. Hoppe (5) states that, in the determination by the phenoldisulfonic acid method using a Cenco "Photelometer," reagent quality phenoldisulfonic acid may be substituted for the synthesized acid prepared as outlined in *Standard Methods*.

The procedure employed in the New Hampshire State Department of Health laboratory involves the evaporation of 20 ml. of sample to dryness. All precautions relative to excessive alkalinity, color, nitrites and chlorides are observed as outlined in *Standard Methods*. To the evaporated residue is added 0.3 ml. of freshly prepared phenoldisulfonic acid (this being sufficient to react with all concentrations of nitrate-nitrogen as plotted on the analytical curve) and the mixture is well rubbed with a glass rod to insure complete contact.

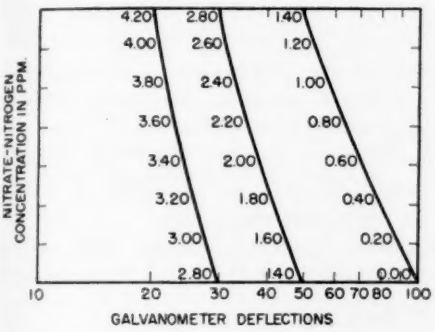
Five to 10 ml. of distilled water are then added, followed by 2 ml. of 12 *N* ammonium hydroxide. Use of the latter was found to be more satisfactory than potassium hydroxide, as the resulting solutions are, in the majority of cases, clearer, thus making filtration unnecessary. The solution is next diluted with distilled water to a volume of 20 ml. and finally compared in the filter photometer. The concentrations can then be read from the analytical curve.

The filter photometer used in these determinations is a Cenco-Sheard-Sanford "Photelometer," equipped with 1-cm. fused cells and a Cenco No. 1 blue filter having a maximum transmission at 410 mμ.

If desired, 100 ml. of sample may be carried through the same procedure, provided adjustments are made in the volume of phenoldisulfonic acid and ammonium hydroxide used. The final volume of solution is adjusted to 100 ml., a portion of which is then compared in the filter photometer. The

authors have found that where a large number of private wells are examined the nitrates are liable to run much higher than in the normal run of public supplies. Hence, the use of 20 ml. is recommended.

The standard nitrate solution is prepared as directed in *Standard Methods* with the exception that ammonium hydroxide is substituted for potassium hydroxide. Prepared dilutions are made from the stock nitrate solution and these dilutions are increased to 20 ml. after 2 ml. of 12 *N* ammonium hydroxide has been added to develop the maximum yellow color. The dilutions



are finally placed in the 1-cm. fused cells and the corresponding transmission read from the "Photelometer." The analytical curve is then drawn from the data recorded, as can be seen in the figure.

To check compliance with *Standard Methods,* the foregoing procedure was repeated, using 12 *N* potassium hydroxide in place of ammonium hydroxide. It was observed that the analytical curve obtained superimposed the original ammonium hydroxide curve, from which it was evident that each of these reagents affords the same intensity of color.

Before readings are made on the "Photelometer," the instrument is adjusted so as to give a reading of 100 with distilled water. The reading is to be considered as maximum transmission for the filter system used. It was observed that when 2 ml. of ammonium or potassium hydroxide are increased to 20 ml. by the addition of distilled water, a reading of 100 is recorded on the "Photelometer." This reading indicates that no transmission error is introduced by the addition of the caustic.

In order to record concentrations in the order of 0.01 ppm., it was found necessary to run a blank on each new batch of phenoldisulfonic acid. When 0.3 ml. of phenoldisulfonic acid is added to distilled water, then made alkaline with 2 ml. of 12 *N* ammonium or potassium hydroxide and finally diluted to 20 ml. with distilled water, a reading on the "Photelometer" is recorded indicating a nitrate-nitrogen concentration varying from 0.02 to 0.05 ppm., depending on the quality of the reagents. Rather than prepare a new analytical curve for each new batch of prepared acid, the blank is subtracted from each recorded concentration. It was found advisable to determine the blank on the stock acid at periodic intervals. The concentration of phenoldisulfonic acid used in the preparation of the standards is so small that no correction need be applied at this point.

It is interesting to note whether or not this standard yellow-colored solution is in obeyance to Beer's Law (6).

Beer's Law applied to the "Photelometer" can be mathematically expressed as

$$K = -\frac{1}{cxl} \log_{10} \frac{P}{100}$$

where K is the "Photelometer extinc-

tion coefficient," c is the concentration in parts per million, l is the length of the cell path in centimeters and P is the galvanometer deflection, provided the instrument is adjusted to give a deflection of 100, using distilled water as the standard for maximum transmission.

As can be seen from the figure, concentrations are plotted against "Photelometer" readings on semi-logarithmic paper, this being equivalent to the plotting of concentrations against densities. Provided a monochromatic light source is available and Beer's Law is in obeyance, this graph should be linear in character. Due to stray light effects present in filter photometers one would not expect the curve to be linear in character, even if Beer's Law were in strict obeyance (*7*). In fact, one would anticipate the curve to be concave upward, as shown in the figure.

Conclusions

(1) The intensity of the yellow color characteristic of the phenoldisulfonic acid method is of the same magnitude whether it is formed from 12 N ammonium or from potassium hydroxide.

(2) It is advisable to determine a blank on all new batches of synthesized phenoldisulfonic acid and apply the correction to the final concentration.

(3) The standard solutions prepared for photometric readings using the Cenco "Photelometer" with the No. 1 blue filter can be considered to be in close obeyance to Beer's law.

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A Photometric Method for the Determination of Lead in Water

By A. V. A. Munton, H. H. Wittenberg and G. K. Crowell

Div. of Chemistry and Sanitation, New Hampshire State Dept. of Health, Concord, N.H.

A Contribution

THE photometric method for the determination of lead in water is based on the formation of the lead-dithizone color complex. The procedure employed is based on the "mixed color" (1) method. The lead present in the water sample is extracted with the dithizone-chloroform reagent, the excess of which is allowed to partition between the aqueous and the solvent fraction. The color of the extract is thus changed according to the amounts of lead and dithizone present. Clifford and Wichmann (1) state that, "If the extraction is made under definite conditions of volume and strength of dithizone solution and volume and pH of aqueous fraction, the 'mixed color' obtained is definite and reproducible, and, provided excess dithizone is present, depends only upon the amount of lead."

A routine method in which the preparation of reagents does not consume too much time demands adherence to certain precautions to assure their freedom from lead. Hence it is necessary to observe strictly instructions that reagents be "redistilled and repurified," whenever the words appear.

Dithizone Reagent

Dissolve 50 mg. of repurified (2) diphenylthiocarbazone in sufficient redistilled U.S.P. chloroform (redistill from all-glass, pyrex still—Corning all-glass still No. 3360 recommended) to make 1 l. Adjust volume of solution and keep at fairly constant refrigerator temperature, approximately 10°C.

Ammonia Reagent

Dissolve 10 g. of cp. KCN and 10 g. of cp. citric acid in 500 ml. of 28-per cent ammonia, dilute to 1 l. with special distilled, lead-free water (redistill water from all-glass pyrex still).

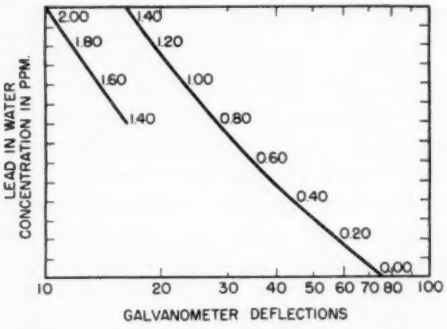
The small amounts of lead normally found in the above cp. reagents have been found to be insignificant to the analysis. Hence, it is not necessary to repurify these reagents unless a definite red color is imparted to the standard dithizone solution when the two are shaken together.

The reagent is stored in a pyrex bottle and dispensed from all-glass pyrex equipment.

Standard Lead Reagent

Dissolve 15.9855 g. of dry, recrystallized (2) lead nitrate in 1 l. of special distilled lead-free water which has been acidified with 1 ml. of concentrated redistilled (free of nitrous fumes) nitric acid. This solution will contain 10 mg. of lead per ml. From it prepare a more dilute (working) solution containing 0.01 mg. lead per ml., using special distilled lead-free water as the solvent.

The filter photometer used in these determinations was a Cenco-Sheard-Sanford "Photelometer" equipped with 20-ml./1-cm. Klett absorption cells and a Cenco No. 1 blue filter having a maximum transmission at 410 mμ. The blue filter was used in preference to the green (525 mμ) for the reason that a greater range of galvanometer deflections was obtained. Before readings were made on the "Photelometer," the instrument was adjusted to give a reading of 100 with special distilled lead-free water. This is to be considered as maximum transmission for the filter system used.



From the standard lead "working solution" prepare concentrations of lead ranging from 0 to 0.20 mg. Make final volume adjustment to 100 ml. with special distilled, lead-free water.

To the 100-ml. standards add 10 ml. of the ammonia reagent, followed by the addition of exactly 15 ml. of the cold dithizone reagent. Shake vigorously (100 times has proved to be sufficient for complete transfer) and allow layers to separate. Filter the chloroform layer through Whatman No. 12 (12.5-cm.) folded filter paper. Place the filtered chloroform solution in the absorption cell and record the galvanometer deflections. Plot galvanometer deflections against concentrations on semi-logarithmic paper.

The unknown sample is treated in the same manner and the corresponding concentration taken from the analytical curve.

Summary

While dithizone will react in an alkaline-citrated solution with a number of metals, the presence of an excess of potassium cyanide will prevent reaction with all but bismuth, thallium, stannous tin and lead.

Since bismuth and thallium are not frequently encountered in potable water supplies, the presence of stannous tin appears to be the only important offender. The presence or absence of this metal must be confirmed before a positive or negative lead finding can be recorded. The presence of this metal in normal distilled water has compelled the authors to redistill all distilled water from all-glass pyrex stills before it could be used in lead determinations.

When utilizing the "mixed-color" method it is imperative that the pH of the solution be 9.5–10.0 before the dithizone reagent is added. Although the authors have never experienced a water that did not exhibit this pH after addition of the ammonia reagent, it is important that this condition be met, to avoid dissociation of the lead-dithizone complex.

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Water Treatment at the Institute, W. Va., Synthetic Rubber Plant

By E. Leonard Borg

Tech. Supt., Synthetic Rubber Div., United States Rubber Co., Institute, W.Va.

Presented on Oct. 26, 1944, at the West Virginia Section Meeting, Parkersburg, W.Va.

THE government-owned synthetic rubber plant at Institute, W.Va., occupies a 38-acre plot on the north bank of the Kanawha River in Kanawha County, at a point about 10 mi. west of, and downstream from, the city of Charleston. This plant, capable of meeting 20 per cent of this nation's average annual peacetime demand for rubber, is operated by United States Rubber Co., agent for the Rubber Reserve Co. Construction of the plant was started in September 1942, synthetic rubber was first produced in March 1943, and the plant has operated at greater than designed capacity since December 1943.

The plant site was selected for the abundance, in the Kanawha Valley, of certain of the raw materials which go into the production of synthetic rubber. These and other raw materials had already attracted to the Kanawha Valley many manufacturers of chemicals and chemical products to make the area one of the great centers of the chemical industry in America. The industrial area of the valley extends from Alloy in the east to Nitro in the west, a distance of from 40 to 50 mi. The Kanawha River represents the chief source of water for all of the chemical plants in the area. The river also serves to carry the treated and untreated wastes from the plants. Institute is located at almost the western or downstream end of the Kanwha Valley industrial belt.

As might be expected, the lower Kanawha River carries considerable industrial contamination. In addition, the great population center of Charleston, with over 100,000 inhabitants, is located on the Kanawha River near the center of the industrial area. Charleston and its surrounding communities discharge their untreated sewerage into the river, adding domestic contamination to the industrial contamination and creating a serious pollution hazard, particularly during periods of low flow in the Kanawha River, for those plants and communities located in the western portion of the valley.

Where it passes the synthetic rubber plant at Institute, the Kanawha River is 600 ft. wide and has a channel depth of 20 ft. Here the river is at a stage between two navigational and power dams, one at Marmet and one at Winfield. The mean flow at this point is 15,000 sec.ft., equivalent to 7,000,000 gpm. The maximum flow during the high water of 1940 was 216,000 sec.ft. and a minimum flow of 650 sec.ft. was recorded in 1930. In the month of October 1943, a low flow of 1,400 sec. ft. was recorded. During periods of such low flows the river will sometimes be "pooled up" behind the Winfield

dam in order to maintain the desired stage. Water treatment problems are naturally most difficult during such periods.

When the site for the construction of the synthetic rubber plant was selected, the Kanawha River was selected as the source of all water. The synthetic rubber process requires water of two types—an abundant supply of cool, clean water for use in taking up process heat from jacketed vessels and condensers (circulating water); and a lesser supply of carefully treated water for use in the actual preparation of the synthetic rubber (treated water).

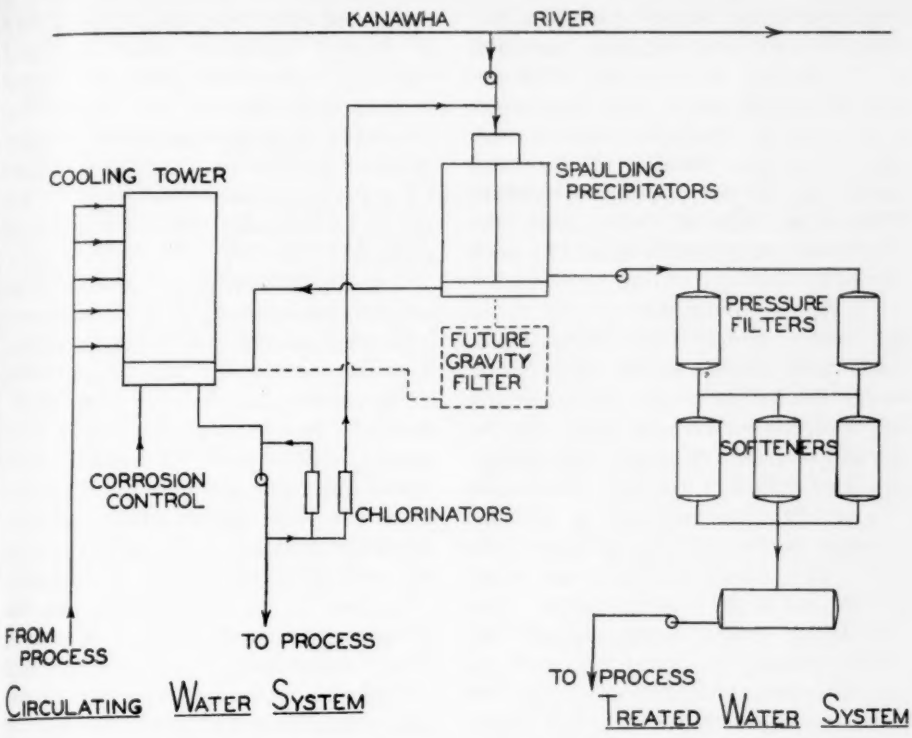
Circulating Water System

Kanawha River water is pumped at the rate of approximately 2,000 gpm. by Carbide & Carbon Chemicals Corp. to the first unit of the water treatment plant—one that is common to both the circulating and treated water systems —the Spaulding precipitators. Before entering the settling basins the incoming water is chlorinated beyond the break-point to a 1- or 2-ppm. flash chlorine residual. Break-point chlorination at this point is related more closely to the treated water system and will be discussed in detail later. However, the chlorination permits operation of the precipitators with a lower charge of alum and precludes the possibility of slime and algae growth on the walls of the settling basins. The 90-minute holdup time in the settling basins is sufficient for complete break-point chlorination. At the present time, with ammonia nitrogen in the Kanawha River running between 2 and 4 ppm., break-point chlorination of the total incoming water requires about 800 lb. of chlorine per day. A high ammonia nitrogen of 12 ppm. has been measured in the laboratory.

Alum and soda ash are added at the Spaulding precipitators for clarification of the river water and control of pH. During periods of low river turbidity it is sometimes necessary to add clay to the incoming river water in order to hold down the sludge. The clarified water, at a pH of 7.0 to 7.5 and containing less than 25-ppm. turbidity, flows by gravity into the pump suction chamber at one end of the cooling tower. At the present time there is under construction an anthracite gravity filter between the Spaulding precipitators and the pump suction bay. This equipment will further reduce clarified water turbidity.

In the pump suction bay are added those chemicals required for corrosion control in the circulating water system. Prior to May 1944, corrosion control had not received much attention. At that time corrosion, tuberculation and pitting of heat-transfer surfaces, together with fouling of condensers, made necessary a complete cleanout of the entire circulating water system with inhibited acid. At the time of the cleanout, a saturation index was adopted as a measure of the corrosive and scale-forming tendencies of the circulating water.

The U.S. Rubber Co. maintains a saturation index of plus 0.3 to plus 0.7 at 80°F. in the circulating water system. This renders the water scale-forming rather than corrosive and a thin calcium carbonate film has been laid down throughout the system. To prevent this scale from building up to such a thickness as to lower heat transfer, a small heat exchanger complete with thermocouples has been installed in the circulating water system on which a daily heat transfer coefficient is calculated. A steady decrease in heat transfer coefficient, as measured



Flow Sheet of Water Plant of United States Rubber Co., Institute, W.Va.

on this equipment, is a signal to lower the saturation index somewhat, thereby rendering the circulating water less scale forming. Scale already laid down can be carefully removed by operating at a negative saturation index and watching progress by use of the small heat exchanger. Under conditions of negative saturation index the water is corrosive and any exposed parent metal will be attacked. At such times the measurement of soluble iron content in the circulating water system is a valuable tool for the water plant operator.

The saturation index can be maintained by controlling the pH, the hardness or a combination of both. When the hardness of the Kanawha River water is above about 70 ppm., a positive saturation index can be maintained by pH adjustment alone. This is done by adding a soda ash solution to the pump suction bay. When the hardness of the river water is below 70 ppm., a positive saturation index can be maintained by the addition of a slurry of hydrated lime, alone or in combination with soda ash. In either case the final measurement and control of the saturation index is from a pH recorder located at the discharge of the circulating water pumps.

From the pump suction bay the water enters a battery of circulating water pumps which move it at the rate of 40,000 gpm. through the many pieces of process equipment in the plant which

require cooling water. Some of this water is used in a washing operation in the factory and is lost. The remainder enters underground reservoirs from which it is pumped over the cooling tower for removal of the heat picked up in the process equipment. This is an induced draft tower, the draft being provided by nine fans, each driven by a 60-hp. motor.

In passing over the cooling tower the water temperature drops 10°F. The catch basin under the cooling tower discharges to the pump suction bay and this water is re-used. At the suction of the circulating water pumps is added sufficient chlorine (about 100 lb. per day) to maintain a chlorine residual in the circulating water system. The chlorine added is equivalent to that lost in the cooling system. The circulating water pumps supply the small quantity of water necessary to operate this chlorinator and the one used to chlorinate the incoming water.

Treated Water

The treated water system really begins with the chlorination of the incoming water, since it is in the interests of treated water quality alone that the raw water is break-point chlorinated. During a period of extremely low flow in the Kanawha River in October 1943, the synthetic rubber latex showed a tendency to coagulate in tanks, pipelines and other pieces of plant equipment. This condition was extremely troublesome and threatened to interfere with the production of synthetic rubber at a time when that material was so urgently needed. An intensive investigation in the plant and in the laboratory confirmed suspicions that water quality was to blame for the trouble. Continuing investigations to isolate and name the troublemaker in the water have been unsuccessful. It is known, however, that excessive hardness (above 50 ppm.) will cause trouble and that organic matter as measured by a permanganate oxygen demand greater than 3 ppm. is bad. Of the two, organic matter is by far the worst offender and the hardest to control.

Experiments on waters known to be of poor quality revealed that treatment with mercuric chloride did not result in a satisfactory water, thus eliminating living bacteria as a possible cause of the trouble. In all cases where these poor quality waters were chlorinated, however, they showed definite improvement and those waters which had been super-chlorinated were, almost without exception, completely satisfactory. This led to an investigation of the break-point characteristics of Kanawha River water and to the purchase and installation of equipment for break-point chlorination of the entire flow of raw water.

The feed for the treated water system is from the end of one of the Spaulding precipitators. Here 200 gpm. of the clear water is taken from near the top of one of the settling basins and pumped through a pair of pressure sand filters in parallel. The water then goes through three zeolite softeners also in parallel and to a surge tank for use as needed. The natural zeolite greensand is used and recent tests made in the laboratory indicate that a flash chlorine residual of as high as 16 ppm. will in no way affect the softening properties of the zeolite. The zeolite will, however, remove 75 per cent of the chlorine residual from the water as it passes through. No difficulty is expected in passing heavily chlorinated water through the greensand. The hardness of the treated

water is maintained at zero ppm., the greensand being regenerated with brine to maintain this condition.

Water is the largest tonnage raw material in the synthetic rubber industry and in many other industries where it is seldom thought of as such. A complete understanding of the quantity and quality of the water resources and requirements are prerequisites to the design and location of almost any new industry. As industry exploits the nation's water resources to an ever increasing extent, increasing care will be necessary to assure that the available supply is carefully used to prevent waste. In addition, it will become increasingly important that all waste water returned to source be as free of contaminants as it is possible to make it.

Hydraulic Bookkeeping by the Bernoulli Method

By Louis Mitchell

Dean, College of Applied Science, Syracuse Univ., Syracuse, N.Y.

Presented on Apr. 28, 1944, at the New York Section Meeting, Utica, N.Y.

BERNOULLI'S theorem is a highly useful aid in the solution of problems involving the flow of water and other fluids. This theorem, which was first stated by Daniel Bernoulli, a Swiss mathematician, in 1738, is defined as "the proposition that in a flowing stream, the sum of the velocity head, the pressure head and the elevation, at one point, is equal to their sum at another point in the direction of flow from the first point, plus the head lost due to friction between the two points."

The theorem is based upon a fundamental principle known as the law of the conservation of energy, which is defined as "the principle that the total amount of energy in an isolated system remains unchanged while internal changes of any kind occur." More simply stated, it means that the total energy at different points in any mechanical system must always be the same. Thus, at any two points there is an equality between the sum totals of the energy at each point. One total balances the other.

It is a principle of accounting that financial statements must be always in balance. Thus, in balance sheets, assets are equally matched against liabilities, receipts against disbursements and, in trial balances, the total debits must equal the sum of the credits.

Bernoulli's theorem, in which energy can be thought of as a kind of hydraulic currency, is analogous to the principle of balance in financial accounts. By imagining that energy accounts are business transactions, it may serve to clarify the meaning of the theorem and make its application to problems relating to the flow of liquids more easily understood.

Energy is defined as the capacity for performing work. For fluids in motion there are four forms of mechanical energy—kinetic, pressure, potential and heat.

Kinetic energy is associated with motion and is a function of velocity. A bullet which is fired from a gun and speeds through the air possesses kinetic energy. If the projectile strikes a tree its course is abruptly stopped and the kinetic energy is suddenly converted into heat energy. Water flowing in a pipeline or issuing from a nozzle at the end of a hose has kinetic energy by virtue of its velocity.

Potential energy is energy that is dormant but which is ready to go to work the instant the call is given. This type of energy in water is due to its elevation above some given datum plane. By contrast, kinetic energy is active but potential energy is inactive.

Pressure energy exists in the water of a closed pipe when it is subjected to pressure. Pressure energy is a func-

tion of the unit pressure which can be determined by a pressure gage or computed from the measured height of water in a tube attached to the pipe. Given the gage pressure, the equivalent head of water can be easily computed. Pressure energy is essentially a form of potential energy.

Heat energy in flowing water is produced by friction and since this kind of energy is usually absorbed by the water and dissipated in the flowing stream or through the pipe walls, it is called in hydraulics "lost" energy.

Using the following symbols, the equations for these four forms of energy are stated and described as follows, using the foot-pound-second system and water as the liquid.

$$\text{Kinetic energy} = Qw\,\frac{V^2}{2g}$$

$$\text{Pressure energy} = Qw\,p/w$$

$$\text{Potential energy} = Qw\,Z$$

$$\text{Lost energy} = Qw\,h$$

v = velocity in feet per second

w = unit weight of water, viz., 62.5 lb. per cu. ft.

Q = quantity of flow in cubic feet per second

A = area of water cross-section of pipe or channel in square feet

p = unit pressure, in pounds per square inch

h = head in feet, lost by friction

Z = difference in elevation in feet

z_1 and z_2 = elevations at any points 1 and 2, respectively

g = rate of acceleration due to gravity, viz., 32.2 fps. per sec.

C = constant

Under conditions of steady flow it will be noted that kinetic energy varies with the square of the velocity. Pressure and potential energy vary directly with unit pressure and elevation, respectively.

For "ideal" conditions of no friction loss, Bernoulli's theorem can be expressed by the following statement: The sum of Kinetic Energy + Pressure Energy + Potential Energy is a constant amount. As an equation, the statement would read:

$$Qw\,\frac{V^2}{2g} + Qw\,\frac{p}{w} + Qw\,Z = \text{Constant or } C$$

Considering flow between any two points, 1 and 2, in the direction of flow, the energy equation would be written:

$$Qw\,\frac{V_1^2}{2g} + Qw\,\frac{p_1}{w} + Qw\,Z_1 = Qw\,\frac{V_2^2}{2g} + Qw\,\frac{p_2}{w} + Qw\,Z_2$$

Since the factors Qw are common to each term in the equation, the formula becomes an equation in conservation of head, and may be written:

$$\frac{V_1^2}{2g} + \frac{p_1}{w} + Z_1 = \frac{V_2^2}{2g} + \frac{p_2}{w} + Z_2 = C$$

With the elimination of the term Qw, the terms $V^2 \div 2g$, $p \div w$ and Z, remain as linear distances called "heads" which can be plotted vertically to show their relationship to various flow conditions. However, each of the terms represents the amount of energy per pound of water.

As an introduction to energy accountancy, let us use money "energy" and assume that we started out in the morning with $10.00 and make several

exchanges of our funds, without spending or losing any during the day. In the evening, our account for the day's transactions might read:

TABLE 1a

Coins	A.M.	P.M.
Copper	$ 0.40	$ 0.10
Nickel	3.35	2.45
Silver	6.25	7.45
	$10.00	$10.00

In a similar manner, for water under steady flow, we can assume an "ideal" case in which transformations take place in mechanical energy between two points in the direction of flow and, by adopting the accountants' art, set up the tabulation as follows:

TABLE 1b

Kind of Energy	*Number of Energy Units* Point 1	Point 2
Kinetic	0.40	0.10
Pressure	3.35	2.45
Potential	6.25	7.45
	10.00	10.00

While it is, of course, possible to change the forms of "money energy" without affecting the total sum, this would be an "ideal" condition indeed, and with human nature as it is, we would ordinarily expect that some of the money would be spent or lost in the day's transactions. Thus, a more reasonable illustration than that assumed in Table 1a would be as shown in Table 2a.

TABLE 2a

Coins	A.M.	P.M.
Lost or spent		$ 2.55
Copper	$ 0.40	0.10
Nickel	3.35	4.15
Silver	6.25	3.20
	$10.00	$10.00

Energy Transformations

In hydraulic energy transactions, nature's laws are inexorable and the "ideal" conditions of no losses never exist. There is always a "loss," hydraulically speaking, although in applying Bernoulli's theorem the "loss" in reality may be chiefly a conversion of energy into useful work, in addition to losses by friction.

An illustration of this situation might be found in a water power installation where a reaction turbine is in operation. As the water passes through the turbine and causes the runner to rotate, a considerable portion of the energy in the water is drawn off by the revolving shaft of the runner, as useful work.

The total "lost" energy between any two points may be represented in the equation by Qwh, in which h is termed the "lost" head.

Bernoulli's theorem for actual conditions is therefore:

$$\frac{V_1^2}{2g} + \frac{p^1}{w} + Z_1 = \frac{V_2^2}{2g} + \frac{p^2}{w} + Z_2 + h$$

With head loss taken into consideration, Table 1b may be revised to read as shown in Table 2b.

TABLE 2b

Kind of energy	*Units of Energy* Point 1	Point 2
Loss or useful work		2.55
Kinetic	0.40	0.10
Pressure	3.35	4.15
Potential	6.25	3.20
	10.00	10.00

The four forms of energy we have been discussing are also illustrated in Fig. 1 which shows a tank from which water is discharged vertically upward

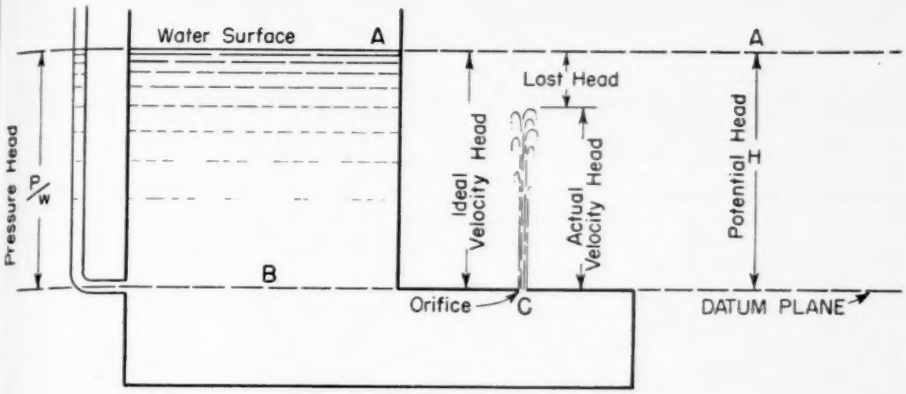


FIGURE 1

from an orifice under a head H, at the rate of Q cubic feet per second.

With the plane of the orifice as the datum plane, the ideal energy present at points A, B and C is as follows:

$A \quad QwH$

$B \quad Qw\ p/w$

$C \quad Qw \dfrac{V_1^2}{2g}$

With V_1 equal to ideal velocity and p/w and $\dfrac{V_1^2}{2g}$ each equal to H.

However, due to friction losses, the actual velocity Va is less than V_1. Therefore the actual velocity head $V_a^2 \div 2g$ is less than H. The difference of $H - V_a^2 \div 2g$ is therefore equal to the lost head. The actual rate of discharge q is less than the ideal Q. Therefore the actual amount of energy is as follows:

$A \quad qw\ H$

$B \quad qw\ p/w$

$C \quad qw \dfrac{V_a^2}{2g}\ Va = qwh$ actual velocity

In order to show by another illustration how energy can be transformed from one type to another, let us assume water is flowing through a pipeline or hose which leads from a reservoir where the water surface is at a constant level and discharges horizontally into the air from a nozzle at the end of the pipeline. Assume further that the profile of the pipeline is as shown in Fig. 2 and that steady flow is taking place without friction losses, i.e., an "ideal" or theoretical condition.

The water surface A in the reservoir is Z feet above the datum plane, and the pipeline at point B passes Y feet above the water level of the reservoir, with Y being less than 34 ft. Thirty-four feet is the equivalent head of water due to atmospheric pressure. Velocities in the pipe and nozzle are v and V respectively, the nozzle velocity being, of course, much greater than the pipe velocity.

Under the conditions that have been described, the total energy at points A, B, C, D and E is identical, although it exists in different forms and amounts at each station.

At point A, the energy is entirely potential, due solely to its position or elevation X above the datum plane.

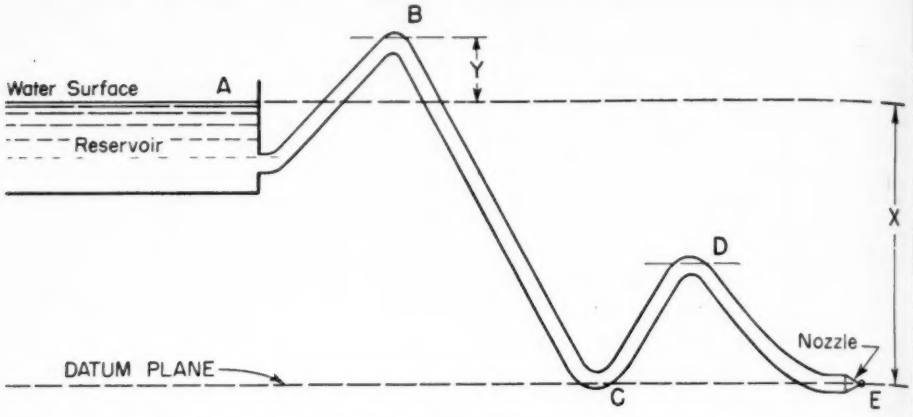


FIGURE 2

Velocity and pressure are absent and the energy is ready to work, but not actually at work. In contrast, at E the energy is all active or kinetic due to the velocity of the stream from the nozzle. At this point potential and pressure energy are absent. The atmospheric pressures at A and E can be disregarded because they are equal.

At point C, the energy is chiefly pressure, except for a relatively small amount of kinetic energy due to the velocity of the water in the pipe. This same amount of kinetic energy is also present at points B and D.

At point B, however, the potential energy is that due to the elevation $(X + Y)$, but the pressure energy at this point is a negative amount and offsets this gain. Therefore, the total energy per pound of water at C is

Kinetic Pressure

$$\frac{v^2}{2g} + -\left(Y + \frac{v^2}{2g}\right)$$

Potential

$$+ X + Y$$ The sum being equal to X.

At point D, kinetic, pressure and potential energy are present, the latter being due to the elevation of the pipe above the datum plane. The remainder is all pressure energy except for a relatively small amount of kinetic energy represented by $v^2 \div 2g$. If D is moved upward, the pressure energy decreases and the potential energy increases. The opposite is true if D is lowered.

Since friction losses will always be present the actual conditions of flow will be considerably different from those represented in Fig. 2. A more realistic representation is presented in Fig. 3, which also shows the pressure line or hydraulic gradient. Friction losses always reduce the "ideal" rate of velocity. Bernoulli's theorem, in its form:

$$\frac{V_1^2}{2g} + p_1/w + Z_2 = \frac{V_2^2}{2g} + p_2/w + Z_2 + h$$

can be used for the solution of any pipe flow problem in which there is one unknown. In many cases, the

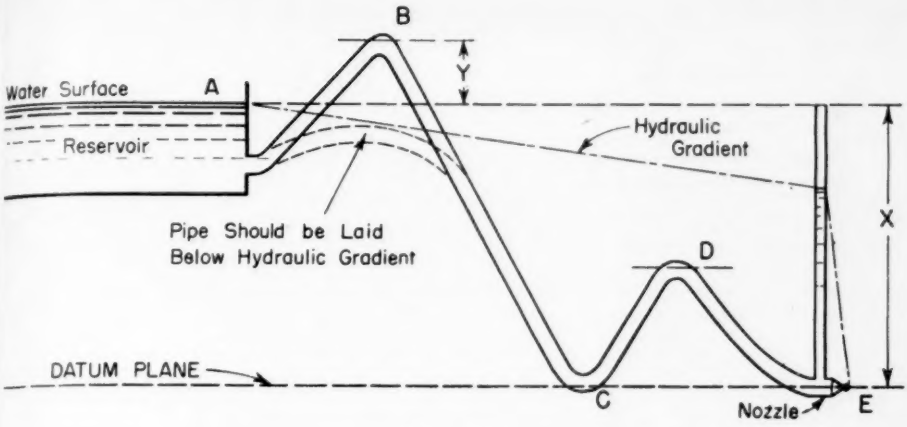


FIGURE 3

problem is simplified by situations where the pipe is of uniform diameter so that $V_1 = V_2$ or in a level position when $Z_1 = Z_2$. If, during steady flow, the unit pressures and corresponding elevations are known at two points on a pipeline of uniform diameter, the head loss between the two points can be readily computed without knowing the rate of discharge. Examples of energy transformations in pipes of uniform diameter are shown in Fig. 4 (a, b and c).

However, if the diameter of the pipe at one point differs from that at the other, Bernoulli's theorem must be supplemented by the following equation based upon the continuity of flow:

$$Q \text{ being constant} = A_1 V_1 = A_2 V_2$$

Illustrations of pipes having different diameters are shown in Fig. 5 (a and b).

Among the practical applications of Bernoulli's theorem which are of special interest to water works engineers, are the Venturi and orifice meters. In 1797, Giovanni Battista Venturi, an Italian scientist, published a statement, based upon Bernoulli's theorem, which pointed out that fluids under pressure gain speed and lose head in passing through converging pipes and vice versa for diverging pipes. In time, this became known as Venturi's Law.

In 1887, Clemens Hershel, an American engineer, patented a device to measure the rate of flow of water based upon this principle and named it the Venturi meter. This meter consists of a converging-diverging tube, and its hydraulic principle is illustrated in Fig. 6. The rate of flow varies as the square root of the difference in pressure heads between the pipe and the throat.

The most significant hydraulic feature is the drop in pressure caused by the increase in velocity throughout the contracted section of the pipe, and its recovery in the expanded section is due to the decrease in velocity. The difference in pressure is measured between the up-stream pipe and the throat because the losses are fairly small in this section.

The orifice meter, Fig. 7, is based upon the same hydraulic principle as the Venturi meter, although a greater

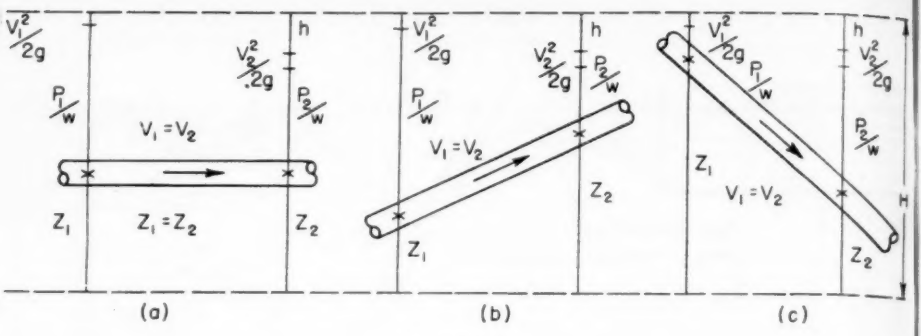


FIGURE 4

loss of head occurs because the water is abruptly crowded through the opening, instead of being gently directed through the contraction as in the Venturi meter. Water, like people, resents being rudely pushed around, and puts up resistance to rough treatment.

Where the pressure in the pipes is low, the pressure heads in Venturi and orifice meters can be measured in piezometer tubes or pipe wells. As a rule, however, this is not practicable, not only because the pressures are too high but because the difference in pressure is what is desired and this can be determined more conveniently by a differential gage.

In addition to the orifice meter, the Bernoulli principle is also applicable to flow nozzles and partial orifice meters. The latter, consisting of segments of circular plates, were successfully developed by E. P. Stewart, Division Engineer of Water Supply, Syracuse, N.Y., on the conduits which supply the city of Syracuse with water from Skaneateles Lake.

Our hydraulic bookkeeping can also be applied to conditions where there is a gain in energy between two points in which water is passing under steady flow. Such a condition would take place where water is being pumped, as shown in Fig. 8. Thus the energy at point 2 would be in excess of that

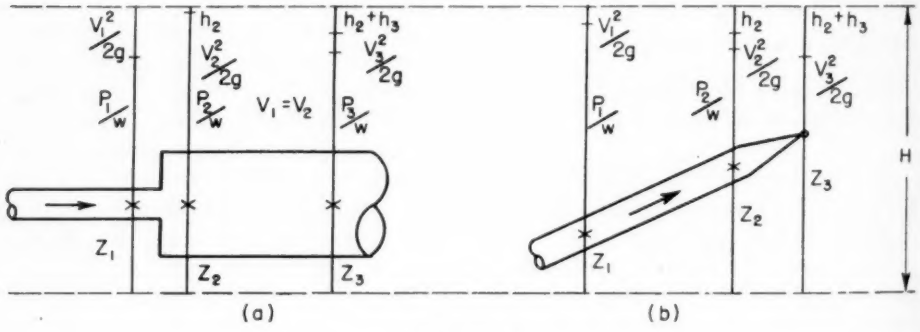


FIGURE 5

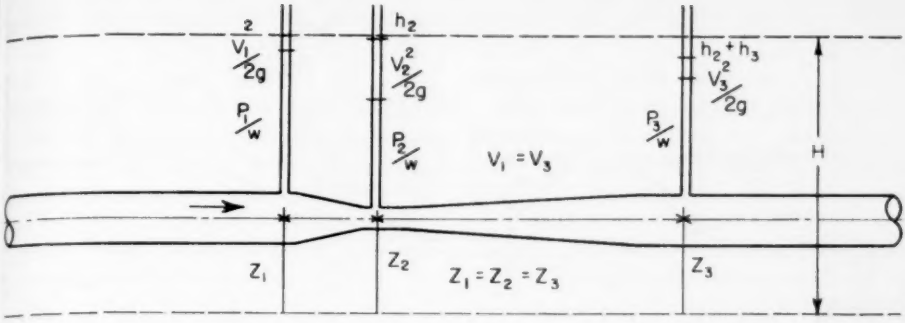


FIGURE 6

at point 1 and Bernoulli's theorem would be modified to read:

$$\frac{V_1^2}{2g} + p_1/w + Z_1 + K = \frac{V_2^2}{2g} + \frac{p^2}{w} + Z_2 + h$$

in which K is the amount of energy added.

In a condensed financial statement, the item of profit and loss appears under liabilities. Supporting statements show the individual items that make up the profit and loss account. In our hydraulic bookkeeping, friction allows no profits and the losses that can be listed may include:

a. loss at entrance
b. loss in pipe
c. loss through valve
d. loss due to sudden enlargement
e. loss due to sudden contraction
f. loss at meter
g. loss through nozzle
h. loss in bends, etc.
i. loss at exit, etc.

In Bernoulli's equations, the total loss can be determined if it is the only unknown. If it is desired to compute some other term in the equation, however, the total loss must be estimated, or, as is usually the case, each individual loss must be taken into consideration. This can be accomplished

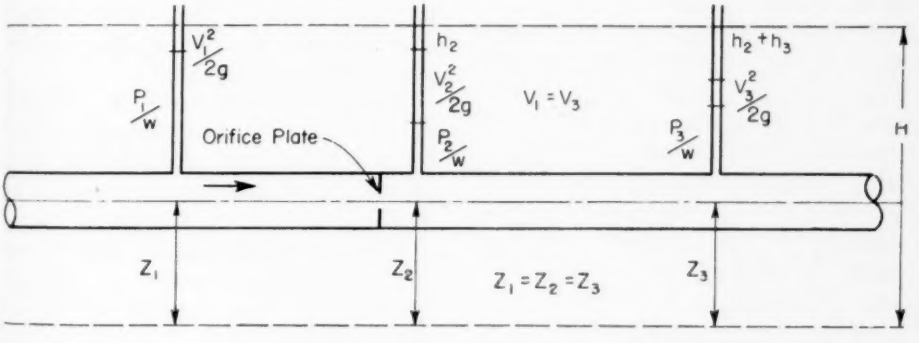


FIGURE 7

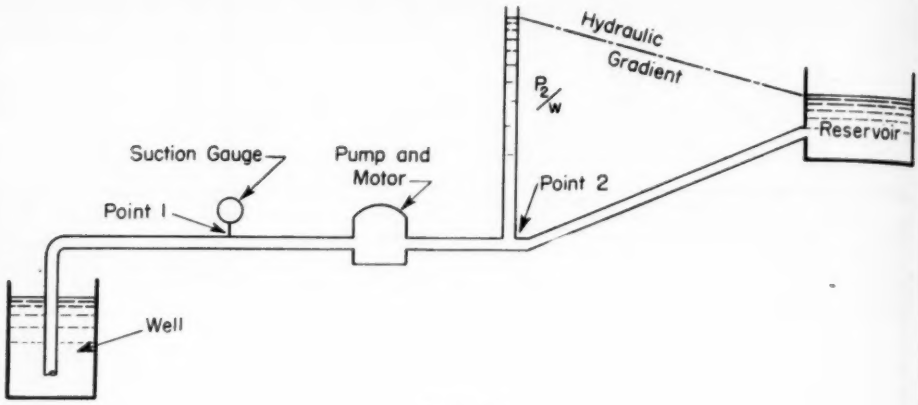


FIGURE 8

by expressing each loss in terms of an equation which includes a velocity head, and assuming some factor for the friction loss. For example: loss at entrance = $KV^2 \div 2g$ in which K usually varies from 0.0 to 0.5, depending upon the nature of the opening.

The use of Bernoulli's theorem is not limited to problems concerning the flow of water in closed conduits. It is a fundamental equation which has many applications. These include the flow of water in open channels, critical velocities, hydraulic jump, etc., and also flow in closed rotating channels such as the vanes of turbine runners and the impellers of centrifugal pumps.

Bernoulli's theorem is also used in the solution of many complex fluid flow problems, where the fluids considered may be oils, air or gases. In such cases, the factors of compressibility, viscosity, temperature, weight and density must be taken into consideration. The theorem is also applied to problems of air and water flow against solid bodies. The former involves studies relating to the design and operation of airplanes, automobiles and trains, and the latter to hulls of ships.

A popular article entitled, "The Parlor Trick That Makes Planes Fly," was published on Jan. 1, 1944, in the *Saturday Evening Post*. Many examples of the Bernoulli effect were mentioned, including the operation of ejectors; the curvings of thrown baseballs by the spinning initiated by the pitcher; and how the weight of an airplane is lifted by the partial vacuum created on the upper curved surfaces of the wings by the air which passes over them. Bernoulli's theorem was credited as having its most important application in aerodynamics.

Bernoulli's theorem is of such importance in the subject of hydraulics that something about its author should be mentioned.

Bernoulli is the name of a family of seventeenth and eighteenth century Swiss scholars and philosophers, nine of whom had distinguished careers in mathematics and the physical sciences.

The family emigrated from Antwerp, Belgium, because of religious persecutions and finally settled in Basel, Switzerland. Among the important members of the family are

the brothers Jakob (1654–1705) and Johann (1667–1748), and Daniel, who was a son of Johann.

Daniel Bernoulli was born on Feb. 9, 1700, in Groningen, Netherlands. He was one of the greatest natural philosophers as well as mathematicians of his time, and, to hydraulic engineers, is best known for his theorem concerning fluid motion, which he demonstrated in 1738.

He was a many-sided genius. As a young man, he studied medicine, received his doctor's degree, and spent seven or eight years at St. Petersburg as professor of mathematics. In 1733, he became professor of anatomy and botany at Basel, and, the following year, he and his father received a double prize from the Academy of Paris for their essay on the causes of the different inclinations of the planetary orbits. In all, he received or shared with others ten prizes from the Academy.

His most important work is his dissertation entitled "Hydrodynamica," which was published in 1738, in which the equilibrium, pressure, reaction and varied velocities of fluids are considered theoretically and practically. Other projects with which he was concerned included an ingenious method of propelling vessels by jets of water ejected from the sterns; construction of a clepsydra or water clock for measuring time at sea; the vibration of chords and the problem of parallelogram of forces.

In 1750, he became Professor of Experimental and Speculative Philosophy at Basel, a position he held until five years before his death in 1782.

Water Works Construction and Maintenance

By Harry E. Jordan

THE American Water Works Association has, for the past year and a half, joined with the New England Water Works Association, the Federation of Sewage Works Associations and the Water and Sewage Works Manufacturers Association in the promotion of postwar improvements for water and sewage works.

During the past two decades water works and sewage works construction have made up 2.6 per cent and 4 per cent respectively of the total public works program in the United States. It is highly essential for persons interested in water supply and sewage works to keep in mind the fact that, while these services are important parts of American public works, their dollar volume in the year by year record of public works construction is much less than roads and streets, bridges, buildings, etc.

It is highly gratifying to observe that as of Dec. 1, 1944, the American Society of Civil Engineers Postwar Construction Committee's summary shows that of public works construction plans under way, water works made up 6.5 per cent and sewage works 14 per cent. Collectively, the two services are shown to be in the planning stage at more than three times their normal proportion in the entire public works field.

Water and sewage works construction can make effective use of labor in the postwar period. The Associated General Contractors of America, in a study released early in 1945, point out that "On water and sewerage projects totaling $1,000,000 at 1940 prices, wages for labor at the construction site would total $318,000, or 31.8 per cent of the total cost, according to statistics compiled by the U.S. Bureau of Labor Statistics. Materials used would total $492,000, or 49.2 per cent, and other expenses, including profit, $190,000, or 19 per cent.

"A total of 330,000 man-hours of labor would be provided on the site, and 430,000 hours off site—in mines, forests, factories, transportation and administration—and about 50 different kinds of materials and equipment would be used in the projects, the tabulation shows."

Another phase of the postwar program for water works relates to maintenance which has been deferred during the 1941–1944 period. Studies have previously been recorded in the JOURNAL (**35**: 539 (1943)), which showed the volume of maintenance and repair in 1940 (prior to war restrictions) and in 1941 and 1942. The quarterly reports for water utilities serving more than 50,000 persons are no longer required by the War Production Board but certain reasonable estimates can be derived from the prior data.

Water Works Maintenance and Repair Materials Used
Dollars per 1000 Persons Served

Year	Source of Supply	Cumulative Deficiency**	Transmission Distribution Meters	Cumulative Deficiency**
1940	$41.32		$380.48	
1941*	35.00	$ 6.00	270.00	$110.00
1942	29.08	12.00	161.89	218.00
1943	22.82	18.50	89.30	291.00
1944*	25.00	16.00	90.00	290.00
Total Deficiency	$52.50			$909.00

* Estimated.
** Figures rounded.

These figures indicate that in the maintenance and repair of water works, the backlog of accumulated deficiencies amounts to more than $960 per 1,000 persons served. In simple terms, it amounts, at the end of four years of restrictions, to approximately $1.00 per person served with public water supply in the U.S. Since there are 85,000,000 persons dependent upon urban water supply, the aggregate dollar volume of deferred maintenance for water works is a very respectable total, even in these billion dollar days. The thing to remember about maintenance is that it does not call for planning and blueprints, but simply a readiness to resume an interrupted program and the "go" signal to the purchasing agent.

Thus we see that whether one thinks of building new works or bringing the maintenance of existing plants up to good condition there is a very substantial contribution to postwar employment that can be made in the water works field.

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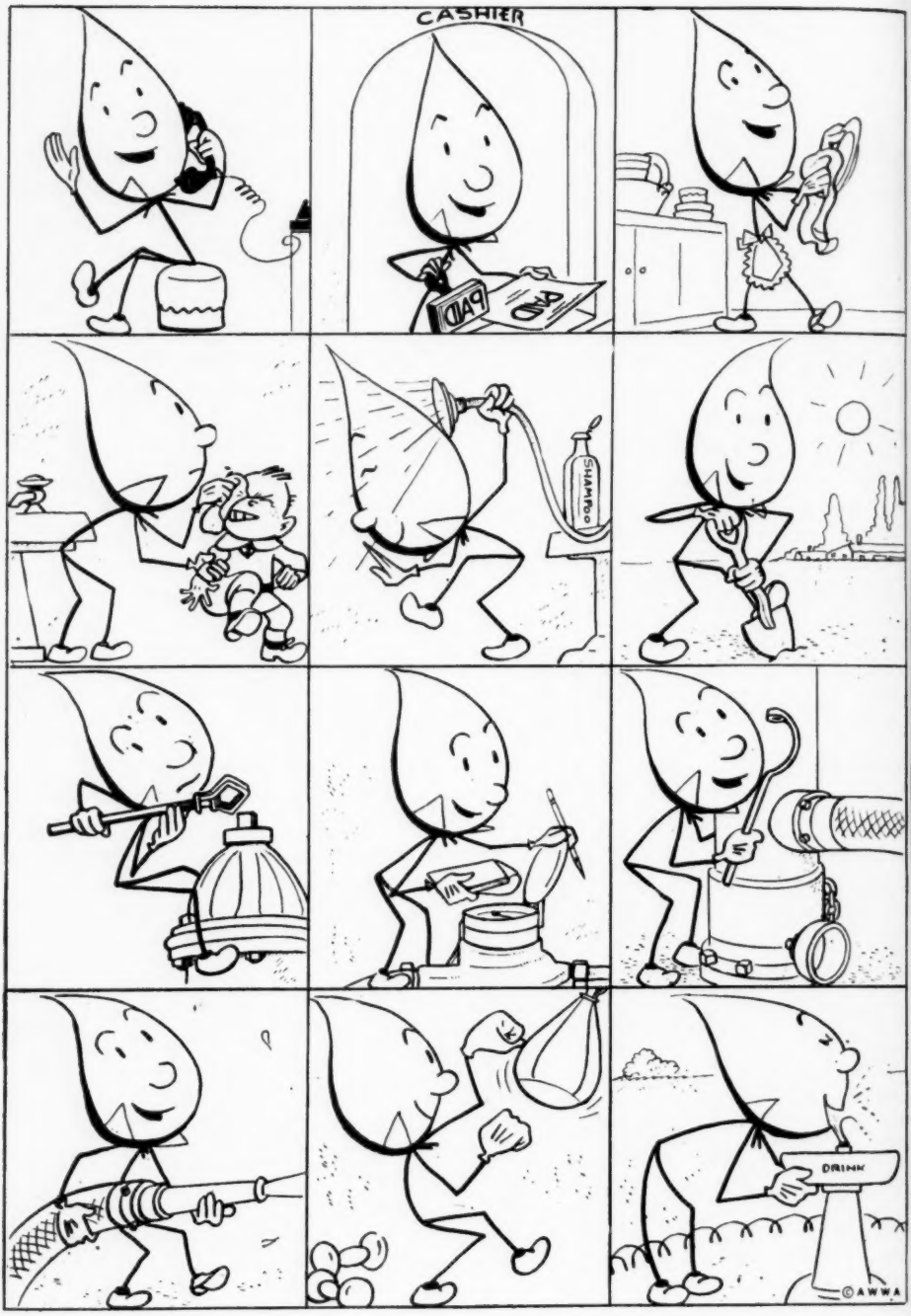

Abstracts of Water Works Literature

Key: In the reference to the publication in which the abstracted article appears, **34:** 412 (Mar. '42) indicates volume 34, page 412, issue dated March 1942. If the publication is paged by the issue, **34:** 3: 56 (Mar. '42) indicates volume 34, number 3, page 56, issue dated March 1942. Initials following an abstract indicate reproduction, by permission, from periodicals, as follows: *B.H.—Bulletin of Hygiene (British); C.A.—Chemical Abstracts; P.H.E.A.—Public Health Engineering Abstracts; W.P.R.—Water Pollution Research (British); I.M.—Institute of Metals (British).*

SOFTENING AND IRON REMOVAL

Removal of Iron and Hardness From Indiana Public Water Supplies. LEO LOUIS. Ind. State Bd. Health Bul. **47:** 195 (Aug. '44). Soils of Indiana, and particularly limestone substrata, in general contribute relatively large amt. of mineral compds. and Indiana's ground waters consequently generally high in hardness and iron. Maps (Figs. 1 and 2) indicate regions of various hardness and iron contents. Water of less than 100 ppm. of hardness considered soft and ideal for domestic and indus. use. From 100 to 200 ppm. hardness not too objectionable. From 200 to 300 ppm., objectionable deposits and other disadvantages of hard water become apparent. Ordinarily conceded that waters of over 300 ppm. too hard. Indiana has many public water supplies with hardness exceeding 400 ppm., and for approx. purposes can be stated that avg. hardness of ground water supplies indicate that this characteristic varies from soft water in auxiliary wells at Odon with hardness of 16 ppm. to hard waters of Jasonville, Orleans and Decatur, where content approx. 1200 to 1400 ppm. Waters high in iron can be traced to regions of glacial deposits in northern section of state and to coal region in southwest. Iron contents under 0.5 ppm. ordinarily will not cause trouble, from 0.5 to 1.0 ppm. may be troublesome, and over 1.0 ppm. will generally cause "red water" and staining. Regions of high iron content include northeast section bounded by Marion, Decatur, Hartford City and Dunkirk, and southwest coal mining section near Bicknell, Shelburn and Jasonville. High iron contents vary from 4 to 6 ppm., with several wells reported to contain iron as high as 12 to 15 ppm. Many wells throughout state, particularly in west central region and southern section, iron free. Freak conditions often noted, such as at Lafayette where public supply wells iron-free while few hundred ft. away, in same Wabash R. bottomland, indus. wells high in this mineral. First responsibility of Ind. State Bd. Health in regard to water supplies is to ascertain that public supplies of safe and satisfactory bact. qual. Potability of supplies secondary consideration, but important for several reasons. For instance, if public water supply high in iron content and discolored or turbid, townspeople will tend to look with disfavor on it, even though it be safe bacteriologically, and will ordinarily seek their drinking water elsewhere, probably from private shallow wells which may be unsafe. In regions of hard water, many cisterns utilized for soft water and either used entirely or cross-connected with house piping. Cistern cross-connections constitute hazard to entire public supply, as well as to occupants of home involved. If public water supply good tasting, clear, odor free and soft, not difficult to convince townspeople that shallow private supplies should be abandoned. Probably, greatest disadvantage of hard water is large quant. of soap or water softener needed to "break" water to form good lather. Corollary to soap usage in laundering is shortened life of linens and other fabrics when washed in hard waters due to soap curds which stick to materials and finally weaken fabrics. Olson states, "Actual records of linen replacements in institutions, hospitals and hotels show from 20 to 50% increase in life of fabrics where soft water used in laundering." Other authorities also state that considerable savings occur from lengthening life of these materials, that materials much brighter and

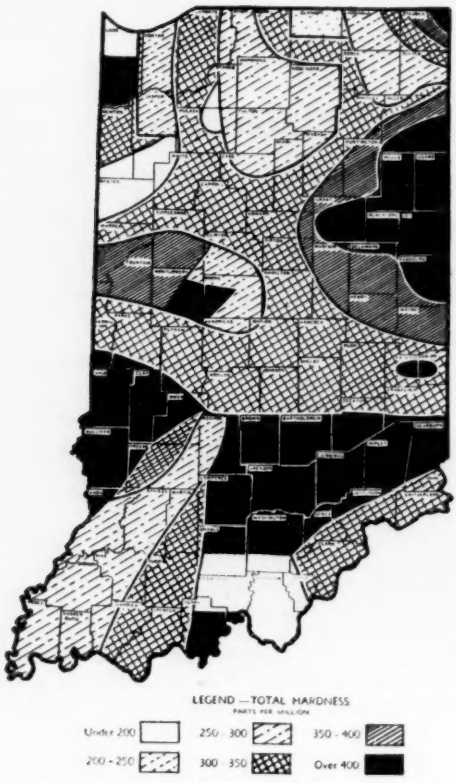

FIG. 1. Map Showing Hardness Characteristics of Indiana's Ground Water Supply

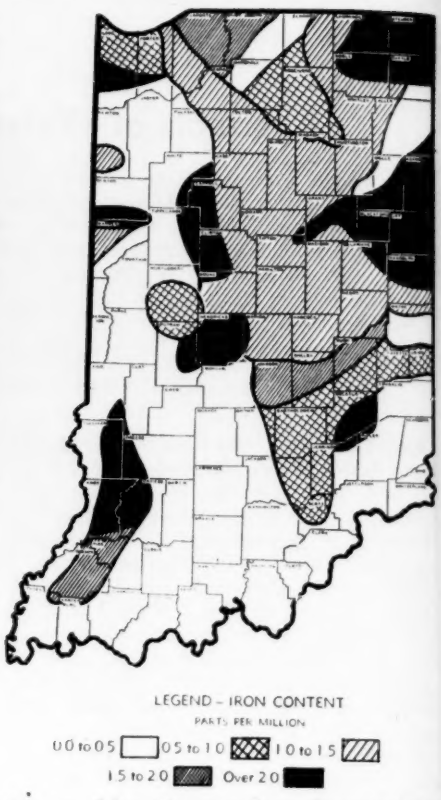

FIG. 2. Map Showing Iron Characteristics of Indiana's Ground Water Supply

cleaner when laundered in soft water, and that time of laundering shortened. Two types of hardness—temporary and permanent. Temporary hardness caused by carbonates and bicarbonates which tend to ppt. from water and form scale when water heated. Apparent in teakettle and all utensils used to heat or boil water. Scale cannot be removed by ordinary washing methods and tends to decrease life of cooking utensils, as well as to lengthen cooking and boiling periods. Same thing happens in furnace coils, hot water heaters and boiler tubes; and replacement cost of coils considerable item. In many communities not uncommon for home owners to install one or two furnace or heater coils every yr. Scale on heater and boiler coils also tends to increase fuel costs and decrease fuel eff. Most industries, institutions and commercial establishments which utilize large steam heating or power plants treat hard waters for use in their boilers and many home owners either purchase or rent individual water softeners. Cost of maintg. individual treatment plants could well be elimd. by constr. of central munic. softening plants. Many city officials object to softening all of public water supply when large percentage of water used for flushing streets, toilets, in industries and other places where hard water not objectionable. However, in those municipalities already served by soft water, noted that over-all advantages of soft water outweigh its waste under above conditions. Another objection often voiced is unpleasant taste sometimes attributed to soft water. Any time chem. qual. of water changed taste is changed. Matter of getting used to differ-

ent tasting water and same condition holds true if one moves from one town to another. Pressure of iron also offers major objections to public water supply, although these objections not so readily measurable in actual cost figures. "Red water" usually distinctive in waters contg. iron in appreciable quants. Source of major complaint to housewife. Stains clothing and these stains difficult or almost impossible to remove. Likewise stains porcelain plumbing fixtures such as toilets, wash basins, sinks and bath tubs. Stains can be removed by hard labor with some types of cleanser or with muriatic acid, but are major source of annoyance. Water unsightly for drinking purposes although in most cases bacteriologically safe. Iron deposits in water mains decrease capac. of mains and sometimes clog small mains or house service pipes until no water will pass through them. In addn., these deposits often serve as good media for growth of certain types of bacteria which further clog mains and services with spongy or "jelly-like" growths and impart unpleasant tastes and odors to water. Water works supt. has serious maint. problem with waters of high iron content, as he must flush mains through fire hydrants frequently, thus wasting large quants. of water; or replace small mains and service pipes when they become clogged. Flushing adds to his troubles as it stirs up system and increases "red water" complaints for few days. In general, high iron contents appear to avg. consumer to be more objectionable than hard water. One Indiana community installed new water works system several yr. ago and unfortunately well water contained several ppm. of iron, which resulted in continuously high-colored water in distr. system. Although town officials had originally secured sufficient no. of potential customers to assure satisfactory financial background, only few of townspeople actually installed service connections after seeing water. This water works heavily in debt at present and cannot meet its financial obligations on revenue bonds. Only iron removal plant can save this water supply from failure. Of 335 public water supplies now serving 346 Indiana communities, 46 are from surface sources and remaining 289 from ground water sources. Although many of surface supplies ordinarily hard, this characteristic varies continuously and hardness only overly objectionable in one or two streams, notably West Fork of White R. Iron removal accomplished by ordinary filtration plant treatment methods in use in practically all surface water supplies. Only one surface supply, Ft. Wayne, includes softening in its treatment plant. Of 289 ground water supplies, 12 include both iron removal and softening, 19 include iron removal only, and 3 include softening only. Softened surface supply serves 5.5% of total pop. having access to public water supply, combined iron removal and softening ground water plants serve 2.12%, iron removal ground water plants serve 7.23% and softened ground water serves 0.48%. Table contains various data regarding several of these plants. From files of Ind. State Bd. of Health, sufficient data selected to indicate need of iron removal and/or softening plants in total of 221 communities. Need for these plants based on total hardness of 275 ppm. or more, and iron content of 1 ppm. or more. Both figures higher than most authorities would recommend, but from practical viewpoint considered to be fairly good criteria. Breakdown indicates 138 combined iron removal and softening plants to serve pop. of 418,414 at total cost of $8,368,280; 14 iron removal projects to serve pop. of 18,670 at total cost of $280,000; and 69 softening plants to serve pop. of 314,181 at total cost of $4,712,715. Cost data estd. at $20 per capita for combined plant and $15 per capita for single treatment. Other data indicate that combined treatment plant constr. would cost from $70,000 to $130,000 for capac. of 1 mil.gal. of water treated per day, taking into consideration size of plant, type of treatment, qual. of raw water, elaborateness of treatment plant, etc. Iron removal usually accomplished by processes of aeration, sedimentation and filtration. Aeration serves to oxidize soluble iron compd. to insoluble ppt. and can be accomplished by sprays, coke trays, compressed air or splash plates. Oxidation also obtained by chlorination. Sedimentation serves to allow iron ppt. to settle out of water and sometimes includes coagulation. Sometimes necessary to use lime or other alk. compd. to speed up process of oxidation in certain waters. Filtration accomplishes final removal of insoluble materials and may consist of pressure or gravity systems utilizing sand, anthrafilt or special zeolites as media. Some systems entirely under pressure and elim. sedimentation, while another uses contact filter. Imperative to use chlorination with any of these treatment processes, both to elim. any danger of contamn. and to minimize bact. growths

Comparative Data on Present Indiana Water Supply Iron Removal and Softening Plants

Pop. of Municipality	Treatment	Capac. *mgd.*	Cost Data	Water Rates	Reduction	
					Iron *ppm.*	Total Hardness *ppm.*
4643	IR & SO by A-Cl-S-RF-ZF:D	1.0	$133,000 Revenue Bonds	Min. ¾" Meter $1/mo. 1st 4000 gal. $0.35/1000 ‡$40/yr. each	Raw.....2.5 Finished..0.1	Raw.....676 Finished...100
6362	IR & SO by A-Cals-US-R-RF-D	1.0	$125,000 From Depreciation and Sinking Funds	Min. ¾" Meter $10/yr. 1st 10,000 gal./mo. $0.25/1000 ‡$25/yr. each	Raw.....2.5 Finished..0.2	Raw.....610 Finished...175
2942	IR & SO by A-PF-PZF-D	0.290	$33,500 From Accumulated Funds	Min. $1.50/Quarter for 3000 gal. $0.40/1000 gal. ‡$40/yr. each	Raw.....3.8 Finished..0.1	Raw.....530 Finished... 88
6946	IR by A-Contact Filter:D	1.73	$16,600 From Depreciation and Sinking Funds	Min. $2/Quarter—10,000 gal. ‡$35/yr. each	Raw.....4.0 Finished..0.3	
1623	IR & SO by A-PF-PZF-D	0.250	$27,000 Revenue Bonds	Min. $1.25/mo. for 2500 gal.	Raw.....1.5 Finished..0.1	Raw.....374 Finished... 68
1606	IR by A-S-PF-D	0.144	$6,000 Revenue Bonds	Min. $1.25/mo. for 2000 gal. ‡$40/yr. each	Raw.....2.0 Finished..0.2	
1811	IR by PA-PF-D	0.300	$8,000 Notes and Surplus	Min. $1 for 2000 gal./mo. ‡Variable lump sum	Raw.....2.5 Finished..0.3	
3729	SO by PZF:D	0.380	$6,000 Revenue Bonds	Min. $1/mo. for 2900 gal. ‡$40/yr. each		Raw.....450 Finished...100
5110	IR & SO by A-S-RF-PZF-D	0.500	$63,000 Revenue Bonds	Min. $1.50/mo. for 2500 gal. ‡$40/yr. each	Raw.....6.0 Finished..0.0	Raw.....450 Finished... 80
3835	IR & SO by A-S-RF-PZF-D	1.0	$60,000 Revenue Bonds	Min. ¾" Meter $0.75/mo.—$0.36/1000 gal. ‡$42/yr. each	Raw.....2.0 Finished..0.0	Raw.....316 Finished... 68
12,432	IR by A-Cal-S-RF-D	3.0	$170,000 From Municipal Light Dept. Funds	Min. ¾" Meter $0.50/mo. 1st 7500 gal. $0.20/1000 gal. ‡$30/yr. each	Raw.....1.5 Finished..0.0	

* For 5 mo. only.
** For 6 mo. only.
*** For part of year only.
† Softening and/or iron removal placed in operation.
‡ Annual unit fire hydrant rental.
IR—Iron Removal
SO—Softening
A—Coke Tray Aeration
PA—Pressure Aeration
C—Coagulation
a—Alum or sodium aluminate
l—Lime
s—Soda Ash
US—Upflow Sedimentation
S—Sedimentation
RF—Gravity Filters
PF—Pressure Filters
ZF—Gravity Zeolite Filters
PZF—Pressure Zeolite Filters
R—Recarbonation
D—Chlorination

Comparative Data on Present Indiana Water Supply Iron Removal and Softening Plants (Continued)

Year	Average Pumpage *mgd.*	Total Services	Total Operating Expense		Treatment Plant Expense	
			Total	Cents per 1000 Gal.	Total	Cents per 1000 Gal.
1935	.440	1138	$16,313.92	10.16	$2,446.44	1.52
†36	.707	1181	21,550.73	8.35	2,485.44	0.96
37	.455	1137	29,102.49	17.56	5,379.63	3.24
38	.400	1158	25,956.69	17.77	5,815.26	3.98
42	.338	1456	26,144.51	21.09	8,903.40	7.17
43	.358	1509	26,767.70	20.50	8,001.53	6.13
1941	1.000 est.	2058	16,411.64	4.50		
†42	0.840 est.	2205	16,808.14	5.60	3,543.98	*3.67
43	0.580	2013	21,502.78	10.10	8,477.65	3.96
1938	.140 est.	773		9.85		
†39	.140 est.	798		13.88	**969.76	5.33
40	.102	833		24.20	1,890.24	5.08
41	.092	855		26.49	1,202.24	3.61
42	.098	865		21.61	2,063.55	5.75
43	.110	877		20.82	2,346.69	5.85
1940	.350	1705		13.58		
†41	.322	1755		14.50		
42	.296	1770		17.52		
43	.281	1779		19.38		
1938	.500 est.	260				
†39	.074	264				
40	.092	288				
41	.079	315				
42	.074	352				
43	.090	360	7,200.00	21.9	1,200.00	3.65
†1942	.025	68				
43	.025	114	1,200.00	13.15		
1938		490				
‡1939						
1943	.090	522	5,900.18	19.67		
1938	0.040	366	8,000.89	55.0		
39	0.041	412	4,574.93	30.5		
†40	0.052	441	5,051.39	26.6		
41	0.051	476	5,591.75	30.0		
42	0.057	498	4,952.36	23.8		
43	0.060	510				
1936	0.108		13,365.68	33.15		
†37	0.091	375	13,308.85	39.93		
38	0.114		12,299.72	29.45		
41	0.334		23,023.02	19.10		3.5
42	0.313	1000	17,845.66	17.13		
43	0.352	1000	18,202.72	14.14		
1938	0.500 est.	968	11,770.37	5.35		
†39	0.329	1013	16,628.89	13.86		
40	0.207	1039	16,226.81	21.40		
41	0.238	1045	14,672.59	16.91		
42	0.254	1050	16,595.52	17.75		4.2
43	0.242	1050	17,292.17	19.58		
1931	1.53		22,923.31	4.10		
†32	1.30		26,390.21	5.56	10,036.09	2.1***
33	1.39		36,681.24	7.23	14,753.75	2.9
41	1.248	3859	36,866.93	8.10	9,403.37	2.06
42	1.231	3878	35,511.14	7.90	9,937.34	2.21
43	1.363	3897	38,768.80	7.76	11,434.83	2.29

on filters. Softening processes separated into 2 methods—chem. pptn. and base exchange through zeolites. In chem. pptn. plant calcium and magnesium carbonates and bicarbonates usually pptd. with lime, calcium sulfates pptd. with soda ash and magnesium sulfates pptd. with combination of lime and soda ash. These chems. thoroughly mixed with raw water, sometimes in presence of coagulating chem., and water then settled and filtered. Water usually not stable and prevents after-pptn. of calcium carbonate in distr. system. Process will not result in zero-soft water as calcium carbonate soluble up to approx. 30 ppm. Zeolites granular materials with property of exchanging calcium and magnesium compd. in raw water to sodium non-hardness compd. Calcium and magnesium absorbed into zeolites and at intervals zeolites must be regenerated with brine soln. so cycle can be continued. Zeolites will remove all hardness and will supply zero-soft water. However, in actual practice, certain percentage of raw water bypassed around softener and combined effluent hardness of from 85 to 100 ppm. maintd. Both softening processes have advantages according to chem. anals. of water, size of plant, operating procedures, and other factors considered by designing engrs. In chem. pptn. type of plant, iron removal can be accomplished with little extra cost by addn. of aeration, while with zeolite plant 2 sets of filters usually needed for combined treatment. In this case also, chlorination important and should be installed with treatment plant. How can cost of treatment be justified? Aside from esthetic values, real financial savings will accrue. Different authorities have studied problem from aspect of savings in soap and water softeners and Olson states that in water softened from 350 to 85 ppm., savings would amt. to $13.44 per yr. per family of five. For pop. of 732,595, estd. to need water softening in Indiana, savings would approx. $1,930,000 per yr. Streeter and Raneri est. savings to be 1.25¢ per capita for each ppm. softened over 85 ppm. This would total $2,420,000. According to Shaw and Chase, softening from 350 to 100 ppm. would save $3.50 per capita per yr., or a total of $2,570,000 per yr. Thus total costs of softening plants could be justified in soap savings alone in approx. 6 yr. Savings as result of iron removal not so easily seen, but savings in purchase of cleansing compd. and muriatic acid for plumbing fixtures and water wasted in flushing hydrants would be considerable. Streeter and Raneri est. savings would avg. $120 per ppm. of iron removed per 1000 pop. per yr. Using avg. of 1.5 ppm. of iron, annual savings in Indiana would be approx. $132,000. Table of plant data indicates operating costs at different plants in state. Comparable data published at various times for plants throughout country, but impossible to set exact figure for operating costs as these costs depend largely on chem. characteristics of water treated and process used for treatment. In practically every case noted no. of service connections increased rapidly after installation of plant and water works operating on right side of ledger. Every water works supt. consulted very well pleased with treatment plant and spot survey of townspeople indicated their pleasure in iron-free or soft water or both. Attempt made to obtain actual data from groceries in regard to decreased sales of soap and water softeners, but impossible in most cases except for statement from mgrs. that these sales, especially softeners, had dropped off considerably. Same true with sale of plumbing fixture cleansers. Several plumbers contacted in towns with softening plants and all stated they had replaced very few furnace and heating coils since treatment plants installed. Commented on having to replace range boilers occasionally, but believed this was due to removal of scale by soft water, thus exposing old perforations in tanks. In towns with iron removal plants, water works supts. especially gratified by decreased main flushing programs and decreased maint. calls on water service connections.—*Ed.*

Britain's Water Supplies: Are They Too Hard? DELWYN G. DAVIES. Surveyor (Br.) **103:** 63 (Feb. 11, '44). Uninformed public incapable of making rational decision. Case quoted of small hard water undertaking which held referendum should water supply be softened. Majority rejected such interference with nature. They were not aware, perhaps, of virtues of softening. Referendum as valueless as Eskimo's views on jungle fever. As regards water supply for postwar houses, housewives of Britain demand "hot water and soft water." Of 718 water works in England and Wales with published records one-fifth collect water of hardness 0–50 ppm., another one-fifth from 50–100, and remaining three-fifths using water from 100–1450 ppm. of hardness. If normal qual. falls between 50

and 100 ppm. hardness then 80% utilize water that is either too hard or too soft. Water of 0–50 ppm. hardness may be plumbosolvent, dangerous to consumers. Aggressiveness becomes increasingly evident where alky. and pH values low, particularly where CO_2 content high. Generally supposed that very soft water derogatory to health, since it lacks calcereous quals. Extra cost of water hardness may equal total cost of water supply. But for rationing, present-day annual soap consumption per capita would be about 16 lb. in hard water (200 ppm.) dist. against 12 lb. in soft water dist. 6% addnl. wear of hard water on clothes not overstatement. Financial disadvantage of excess of 100 ppm. hardness above 100 ppm. no less than 16s. per head per annum. Cost of softening about 2d. per 1000 gal. (Imp.). Saving to consumer by bulk softening no less than 14s. 6d. per head per annum. In sludge blanket process turbid water may be passed through and clarified by floating blanket of limed water into which carbonates in soln. deposited. Of two alternative processes, base exchange more trouble-free than sludge blanket in operation, but latter has one principal advantage, namely, its capac. to clean bacterially and physically during softening process.—*H. E. Babbitt.*

Properties of Detergent Solutions. THOMAS H. VAUGHN & ANTON VITTONE JR. Ind. & Eng. Chem. **35:** 1094 (Oct. '43). Washing tests at 60°C. using 0.1% soap concn. with artificially soiled muslin show detergency, at soap to builder ratio of 2 to 1, to be in descending order as follows: proprietary builder 3, sodium hydroxide, proprietary builder 2, proprietary builder 1, sodium metasilicate, sodium carbonate, trisodium phosphate, modified soda and sodium bicarbonate. At soap to builder ratio of 1 to 1, whiteness retention decreases in order: proprietary builder 2, proprietary builder 1, modified soda, sodium bicarbonate, trisodium phosphate, sodium metasilicate, proprietary builder 3, sodium carbonate and sodium hydroxide. In both lists some builders stand close together. Water softening action and rinsability should also be considered in comparing over-all eff. of laundry builders.—*A. A. Hirsch.*

Synthetic Detergents as Hard Water Soaps in the War Effort. CONRAD J. SUNDE. A.S.T.M. Bul. *No. 125:* 25 (Dec. '43). Gardinols, or fatty alcohol sulfates ($R–OSO_3Na$) derived from cocoanut oils, introduced into America in '30. Later synthetic detergents in commercial use: (1) ester type sulfonates having 12–16 carbon atom radical, $R–COOC_2H_4–SO_3Na$; (2) ester type sulfates, $R–COOH_2CHOHCH_2–OSO_3Na$; (3) fatty acid amide link with sulfonate or sulfate, $R–CONH–C_2H_4–SO_3Na$; and (4) alkylarylsulfonates, $R_x–Ar–SO_3Na$. Ordinary soap sodium or potassium salt of a higher fatty acid varying from 12 (lauric acid) to 18 (stearic acid) carbon atoms, R–COOM, contg. a hydrophobic (oil-soluble) and hydrophilic (water-soluble) part. Solubilizing effect of carboxyl group less than that of sulfate or sulfonate groups. Only few members in homologous series of straight chain fatty acid or of synthetic detergent types give useful cleaning agents. Reversals in Far East curtailed cocoanut oil supplies that contained lauric acid useful for salt water soaps and encouraged development of synthetic detergents. Foresighted prewar developments produced synthetic bar soaps with thiourea binder, but product crumbled after use, was deliquescent and became abrasive. Corrected by adding ordinary soap. New soaps allow salt water washing equal to conventional formulas using soap and alkali in soft water, thereby conserving ship's water. To reduce waste, bar form developed for Navy. Army has synthetic detergent meeting functional requirements. Availability to civilians in near future appears unlikely.—*A. A. Hirsch.*

Studies on Synthetic Detergents. JAY C. HARRIS. A.S.T.M. Bul. *No. 125:* 27 (Dec. '43). Inability of Navy, in Mar. '42, to obtain sufficient bids for salt water soap first focused attention on synthetic detergents. Army uses synthetic detergents in mobile launderies because of variable water conditions, short washing cycle and freedom from dermatitis if apparel incompletely rinsed. Bur. of Ships ad Interim Specification 51-D-7 (INT) for minima of 30% anhydrous soap and 20% synthetic detergent in bar soap approximately 3 times as effective as former salt water soap when compared at 2% concn. Other specifications cover power laundry soap, toilet cake, cleaning compounds for painted surfaces and restricted items. Exptl. wash tests conducted in std. launderometer and deg. of std. soil removal measured by means of photo-elec. photometer. Below 0.8% Santomerse No. 1 (active ingredient essentially

dodecylbenzene sodium sulfonate) increasing hardness in water reduced soil removal. Santomerse No. 3, which contains no sodium sulfate, showed higher soil removal. pH adjustment at 9.5 to 10.5 enhanced cleaning, especially with resistant soils. Combination with tetrasodium pyrophosphate, trisodium phosphate, or their mixtures, yielded results superior to Santomerse alone. Such formulas recommended when sufficient rinsing or a sour permissible. Optimum combination in hard water was Santomerse No. 3, 0.08%; builder, 2%. Santomerse products alone, or with tetrasodium pyrophosphate, poor sea water detergents, especially compared to 51-D-7 product. Best action of 51-D-7 at 2% concn.—*A. A. Hirsch.*

Operational Results of Chemical Water Purification by the Base-Exchange Process. D. BURTSEV. Teplosilovoe Khoz. (U.S.S.R.) **3:** 33 ('41); Chem. Zentr. (Ger.) **II:** 1728 ('42). Review of constr. and results of operation of Russian water treatment plant (with coagulation, liming, clarification, filtration through quartz sand and base-exchange in glauconite filters) revealed following defects: Because coagulation with $FeSO_4$ initially omitted and as result of preheating of raw water with boiler water, glauconite filters became strongly contamd. At water temp. of 35–40° decompn. of glauconite occurred. Reducing temp. of raw water, however, made prelim. purif. more difficult (reaction slowed down, liming incomplete and carbonate hardness increased). Thus, raw water must be introduced at temp. of 80–85° and only after lime treatment should it be cooled. At water temp. of 25° exchange capac. of glauconite increased from 2672 (at higher water temp.) to 3205 deg. (sometimes even to 4100). Exchange capac. depends to large extent on alky. of water (hydroxide), which should amt. to 1.3–1.5°. Reducing alky. from 0.3–0.8° to 0.2° reduced exchange capac. of glauconite by 300–350 deg. *Detn. of alky.* carried out by Pozdnyshev method of adding to water sample 5% of its vol. of a 10% $BaCl_2$ soln., which ppts. all carbonate, and then titrating hydroxide against phenolphthalein. This method found to be reliable in practice, although values obtained in case of coagulated waters too high. Washing of sand filter must be done with air blast, as otherwise carbonate deposit not completely removed. Still better results obtained with marble filter of grain size 1–2.5 mm.—*C.A.*

The Effect of Some Factors on Exchange Reactions in Glauconites. V. S. OVODOV. Trudy Novocherkassk. Inzhenernogo-Meliorat. Inst. (U.S.S.R.) **3:** 39 ('39); Khim. Referat. Zhur. (U.S.S.R.) *No. 10:* 11 ('40). Expts. made with natural sand (d. 2.545, vol. wt. 1.426, porosity 44%, exchange capac. 220–340 l.-deg./kg. of sand). Water used artificially hardened to 60–70° (Ger.) by addn. of $CaSO_4$ soln. Increasing temp. of water decreased exchange capac. of glauconite from 65.5 l.-deg. at 3° to 28.0 l.-deg. at 60° with 45-min. regeneration. Exchange capac. of glauconite increased with increase in temp. of NaCl soln. Time required for regeneration can be reduced to 5–6 min. of contact of NaCl with glauconite.—*C.A.*

Electrolytically Softening Hard Water. ROBERT E. BRIGGS. U.S. 2,341,356 (Feb. 8, '44). In use of electrolytic diaphragm cell having anode and cathode compartments, method of operation employed which involves maintg. flow of hard water to be softened through cathode compartment so that pH of water raised to point (suitably about 10.5) at which at least substantial proportion of hardness-producing constituents pptd., removing ppt. formed, and passing softened water through *portion only* of *anode* compartment of cell to reduce pH of softened water (suitably to about 8).—*C.A.*

The Treatment of Recirculating Cooling Water With Sodium Hexametaphosphate. E. SCHUMANN & P. LANDERS. Wärme (Ger.) **66:** 122 ('43); Chem. Zentr. (Ger.) **II:** 2089 ('43). Addn. of slight amts. of hexametaphosphate increases soly. of $CaCO_3$ to value which is dependent on quant. added and which is lower the higher the temp. of the cooling water and the higher the Ca content of noncarbonate hardness. Addn. of hexametaphosphate retards separation of $CaCO_3$ from supersatd. soln. and prevents formation of scale by deformation of separating calcite crystals. Addn. of 2 mg./l. of hexametaphosphate to concd. Ruhr water displaced equil. for separation of $CaCO_3$ to 14–15° carbonate hardness. In presence of larger amts. of phosphate or when solns. stronger than 0.1% used, thermally insulating Ca metaphosphate sludge formed. Addn. of 2 g. of salt for each cu.m. of fresh water gave satisfactory results in recirculating plant, content of which renewed within 3–4-day period by removal of salts.—*C.A.*

Iron-Removal Plants. RICHARD SCHMIDT. Gas-u. Wasser. (Ger.) **86**: 25 ('43). Closed Fe-removal plants cause later trouble on water-distr. system because of insufficient aeration of water; iron bacteria grow and deposits formed. Aeration sufficient in open Fe-removal plant, so this trouble not encountered. With soft water, low in H_2S and org. matter, Magno mass sometimes used in filters in place of silica so as to remove both CO_2 and Fe. Filters need to be enlarged, however, and aeration not secured. New process using open tanks for simultaneous removal of CO_2, Fe and Mn utilizes satd. lime water. Equil. rapidly secured and water becomes sufficiently alk. so that no Fe dissolved from system.—*C.A.*

Purification of Water by Use of Synthetic Ion-Exchange Resins With pH as a Control. ALVIN L. KENWORTHY & JOHN NELSON HOWARD. Soil Sci. **57**: 293 ('44). Water passed through "Amberlite" comparable and in many respects superior to distd. H_2O, whereas in several respects de-ionized H_2O very comparable to redistd. H_2O. Breakthrough or satn. point for towers filled with such synthetic resin can be detd. by use of ordinary lab. model pH meter. Germination of sporangia of *Phytophthora infestans* Thax. (Guss.) indicates continued adsorption of Cu after cation exchanger satd. and also that the Cu content of H_2O is lower than that of distd. H_2O but not so low as that of redistd. H_2O. —*C.A.*

STERILIZATION

Notes on the Control of Chlorination. A. R. VAIL. Wtr. & Wtr. Eng. (Br.) **46**: 102 (Mar. '43). (*Abstracted*, Jour. A.W.W.A. **35**: 1502 ('43)). *Discussion. Ibid.* **46**: 281 (July '43). In war, as in peace, first line of defense of purity of water supply is control of gathering ground. Protection of water from poln. after leaving works affects subject of paper only insofar as residual to be aimed at in control tests might have to be adjusted to suit any individual case. 0.2 ppm. may be taken as recommended min. residual since smaller amts. extremely difficult to detect. W. C. KNILL: Chlorination foredoomed to failure if control not continual and conscientious. Chlorine flow recorder at each chlorinator, although not indicating residual chlorine in water going into supply, acts as effective check. Sampling of water for anal. must be done to fixed program. If, as author suggests, when nitrites present in water, hypo added in making ortho-tolidine test, color produced by nitrites either not present or considerably reduced. If ammonia present in raw water, engr. might experience difficulties if he relies on simple chlorination, since chloramines would be produced and contact time required would be much higher. In sampling chlorinated water, de-chlorination of water at time of sampling essential. May be done by addn. of crystal of hypo to sample bottle before sterilization. If not done sample will not be representative of water going into distr. system. N. J. PUGH: Experience indicates that if 0.2 ppm. residual to be maintd. throughout distr. system, initial residual ex-works of 0.5 to 0.6 ppm. would be necessary to produce 0.2 ppm. in remote portions of distr. system. If distr. system closed, residual security against malicious poln. but deg. of poln. would be so gross that residual would be inadequate. In effect, such residual might give sense of false security. Presence of such residual largely increased corrosion of ball taps and fittings and increased waste. B. L. MCMILLAN: Factors giving false sense of security when obtaining residual of 0.2 ppm. by o-t. test. To cite a case in explanation: Water in 2 open service reservoirs chlorinated at source and upon entering reservoirs given dose of chloramine. Chlorine disappeared in reservoirs but ammonia carried on. When chlorine added at outlet, chloramine formed and although residual 0.4 ppm., it was chloramine and not chlorine and evidently not sterilizing water. More information required about proper proportion of chlorine to ammonia in chloramination process. C. WALMESLEY: Ordinary unstabilized bleach does not lose its strength rapidly although containers corrode quickly. After storing some ordinary bleach for 2½ yr. in drum and then in about 1-lb. tins, about 35% available chlorine found. Author recommends ratio of chlorine to ammonia in chloramination process of 4 to 1 but I have personally experienced ratios of 5 or 6 to 1, and as low as 3 to 1. 5 or 6 to 1 generally gives best results. Desirable to keep chlorine residual throughout distr. mains but incrustation on mains seems to act as de-chlorinator. With regard to corrosion of fittings by water

contg. free chlorine, to be noted that water which has avg. pH of 6.7 chlorinated in few seconds, dose varying from 0.5 to 1.0 ppm. No corrosion noticeable in pumps handling this water. R. C. S. WALTERS: In one case, after applying 0.5 ppm. and pumping hard water through 20 mi. of pipe, residual of 0.3 ppm. found in reservoir after 15 hr., whereas water of similar qual. after pumping through old incrusted main only 3 mi. long showed no residual after 5 hr. and *Esch. coli* often found in 50 ml. On particular watershed composed of carboniferous limestone qual. of water during dry season satisfactory and free from *Esch. coli*. After heavy thunderstorm fissured limestone brought contamd. water. T. WATERTON: Pointed out that "bleach" complex composition mainly oxychloride of lime. Pleaded for use of proper term "bleach." Primary use of super-chlorination and dechlorination is to treat water in which it is impossible in main layout to get contact time long enough for chloramine or straight chlorine. S. R. RAFFETY: Dissented from view that residual chlorine in mains needed "because something might happen to water" before it got to consumer. Consumer likes taste of chlorine, feels certain safety in it. *Author's Comment:* Residual of 0.2 ppm. given in paper as generalization and could be detected with ordinary comparator. Residual merely indication that one has put in more than enough chlorine. Under war conditions, where qual. of water liable to rapid changes, unless samples analyzed very frequently, anal. not any check on qual. of water. Cases known of even smaller doses than 0.5 ppm. being followed by de-chlorination. Some evidence that hot-pressed metal fittings detrimentally affected by chlorine in water. C. A. SERPELL: Super-chlorination defined as addn. of sufficient chlorine to oxidize all org. matter present in water. This presupposes that simple chlorination effects only partial destruction of organisms present. Deg. of stability of chloramine residual in water measure of residual org. matter present after sterilization. *Author's Closure:* Automatic control of residual desirable, particularly with variable water. If simple chlorination appropriate residual after 30 min. contact indicates sterility. Chloramine treatment more difficult to apply particularly where water has high pH or contains free ammonia. Effect of such ammonia on chlorine not understood. Stds. laid down for U.S. Army in field conform with those set for our own forces, i.e., 1 ppm. residual. Most likely reasons for adopting super-chlorination: heavy poln., variable qual. and lack of adequate contact for simple chlorination.—*H. E. Babbitt.*

Experimental Contributions to Oligodynamic Action With Special Reference to Water Purification. I. OTTO ORNSTEIN. Acta Path. Microbiol. Scand. (Den.) **20**: 1: 86 ('43). Cu and Ag show 2-phase action of salts tested. Frequently, also case with halides, I and Cl. Combinations of Cu and Ag with I and Cl show this property regularly. NaCl in decreasing concns. additively increases Cu and Ag. Tests with distd. water and tap water and filtrates led to belief that effect of chlorination and treatment with $CuCl_2$ and AgCl depends on amt. of chloride Cl and on bi- or higher-valent metal salts (Al), also on H-ion concn. Test objects showed specific sensitivity; staphylococci more sensitive to Cl + NaCl or to Cl + NaCl + Cu and Al than paratyphoid bacilli, but latter more sensitive to $CuCl_2$ and $AlCl_3$. Subtilis spores less sensitive to Cu addn. in chlorination but sensitive to distd. water. Antagonism observed between $CuCl_2$ and Cl(Ag_2SO_4 and Cl), especially between $CuCl_2$ and NaCl. Less striking effects observed with Cl + NaCl; they must be considered as oligodynamic effects of additive character. Greatest just effective diln. of disinfectants depends on chem. substances added with test object in "pure" test with distd. water. These are electrolytes and colloids which especially affect new complex formations of components. Importance of glass and ceramics for complex formation and dissocn. of active ions and as source of errors in "pure" tests explained, especially for bi- and higher-valent chem. substances used for H_2O disinfection, particularly for Al. $AlCl_3$ in concd. solns. has limited action, if reaction acid, but shows sec. oligodynamic action phase at greatest dilns. and slightly alk. reaction. Action greatly increased with NaCl and $CuCl_2$, especially at pH 8. Oligodynamic action based on combination of components, inactive per se, at favorable H-ion concn. In addn. to metals, neutral salts, halides, Si and many other chem. substances analogously active. Oligodynamic action and biol. preventive mechanism closely related chem. processes.—*C.A.*

Experiences With the Cumasina Process in a Central Drinking Water System. Ges. Ingenieur (Ger.) **66**: 20: 305 ('43). Sterilization of water supply for small town through silver brought into solution by direct elec. current and ionization of chlorides present in water. To produce soluble silver and at same time free chlorine for killing of organisms silver plate used as anode and non-corrosive metal as cathode. Process was called "Cumasina," i.e., *cum argento et sine argento*. The system studied consists of a silver basket with 2 silver plates weighing 250–300 g. each as anode and 2 somewhat larger cathodes made from a different metal. Current used 0.4–0.5A. Capac. 50 M^3/hr. Water passes through basket, picks up soluble silver and is retained in tank for 6 hr. Water supposed to contain from 10–20 mgm. silver per M^3. *Esch. coli* reduction after ¼, ½, and 6 hr. was 74, 97.5 and 99.8%.—*Willem Rudolfs.*

Purification of Water by Sterilization. T. B. BYRNE. Surveyor (Br.) **102**: 517 (Dec. 10, '43). 75% of outbreaks of typhoid fever and other water-borne illnesses caused primarily by defects or laxity in treating, storing or distributing water and not to poln. of water at its source. Chief duty of water authority prevention or treatment by efficient sterilization of dangerous contamn. Sterilization now performed almost exclusively by chem. methods which must comply with following: (1) after treatment water must be palatable and have no harmful effects; (2) there must be no ppt. costly and difficult to remove; (3) reagent must be cheap and easy to apply; (4) application must be sensitive and accurate in control; and (5) initial cost should be low. 2 main schools of thought in connection with this branch of water purif. "Sterilizers" claim process destroys all non-sporing bacteria of intestinal origin. "Anti-sterilizers" claim doped water open to condemnation. Third school claims all purif. processes merely retrograde step and that safety lies in securing uncontamd. sources requiring no purif. Aim of any water authority must be directed to insuring const. bact. purity of supply by all available methods.—*H. E. Babbitt.*

Purification of Water by Sterilization. T. B. BYRNE. Civ. Eng. (Br.) **39**: 35 (Feb. '44). Raschig discovered in '07 that by mixing ammonia and bleach soln. one of hydrogen atoms replaced by chlorine, forming monochloramine. Rideal, in '10, showed that first rapid consumption of chlorine succeeded by slower action which went on for days, and even weeks. Monochloramine stable, powerful germicide, and rapid in action. Dichloramine even more stable and powerful, but slower in action. Suckling believes that monochloramine occurs only if pH over 8.5, and that mixture of two occurs at pH values between 4.4 and 8.5. Reasons for germicidal superiority of chloramine reactions obscure. Methods of application of chloramine may be summarized as: (1) previous prepn. of chloramine, i.e., adding free chlorine or hypochlorite to soln. of free ammonia or ammonium salts; (2) simultaneous addn. of chlorine and ammonia in bulk to water; (3) addn. of free ammonia as gas or soln., or ammonium salts in soln., to bulk of water, and subsequent addn. of chlorine, free or as hypochlorite; (4) addn. of free chlorine to water followed by ammonia. Advantages: (1) persistence of sterilizing agent; (2) ease of application; (3) chlorine requirements cut down 50% so that tastes and odors reduced; (4) chloramine has selective action destroying bact. life before becoming absorbed by org. matter; (5) aftergrowth trouble largely elimd.; and (6) owing to reduced dosage slight proportional fluctuations do not produce same variations in amt. of free chlorine. Disadvantages: (1) addnl. expense and complicated plant required; (2) extremely corrosive nature of ammonium salts and gas, reagents expensive; (3) somewhat slow action; (4) failure of ammonia dose may leave chlorine dose insufficient for sterilization; (5) taste and odor difficulties arise if free ammonia content of water high because chlorine dose will need to be much increased, and; (6) misleading reactions with OTO indicator may occur occasionally if ammonia content is in excess and the pH is high.—*H. E. Babbitt.*

A Study of the Suitability of Chemical Warfare Service Activated Carbons for Use in Treatment of Public Water Supplies

By E. H. Mann and C. C. Ruchhoft

Div. of San. Eng., Water and Sanitation Investigations, U.S.P.H.S., Cincinnati, Ohio

Report Published by Permission of the U.S. Public Health Service

Editorial Introduction

The Chemical Warfare Service has released to the Surplus Property Division of the Reconstruction Finance Corporation a considerable tonnage of gas-mask carbon, which is available for sale to civilian agencies having need for such material. Since offers of this material may be made to public water supply agencies, its usefulness for water treatment has been under discussion for about three months.

A study to determine the value of the carbon was made at the U.S. Public Health Service laboratory in Cincinnati and the report is hereinafter published with the permission of the U.S.P.H.S.

The two concluding paragraphs of the report read as follows:

> Samples of these carbons ground to pass 200 mesh were tested for phenol value and odor removal ability. Their phenol values were all over thirty and their odor removal performance compared unfavorably with a good grade of commercial powdered activated carbon. It is concluded therefore that all of these carbons are unsatisfactory for activated carbons classified as of water purification grade upon the basis of phenol and odor removing performance, rather than for any additional hazard that they might introduce because of the silver or copper that they contain.
>
> This study has shown that there is no danger of imparting toxic concentrations of silver or copper to water by treatment with these carbons. It is recommended that the use of Chemical Warfare Service activated carbons containing 0.1 per cent silver and up to 10 per cent copper be permitted for the treatment of public water supplies.

The material as it now exists in various warehouses is granular, ranging from 6- to 30-mesh size. Some of it has been impregnated with copper (type A) and some with copper and silver (type AS). Another grade conforms to Federal Specification 197-52-39D. Information concerning this material is "restricted." Its composition is therefore not publicly known and it cannot be considered for use in water treatment.

The added materials in the various carbons have to do with their value as adsorbents of toxic gases.

Much or most of the available material was made from wood, coconut shells or coal. It is denser than routine water purification activated carbon, weighing 30 to 36 lb. per cu.ft. instead of 18 to 20 lb.

Since the material is now in granular form (6 to 30 mesh), it cannot be used in water treatment (when the carbon

is dispersed in the water) without having been ground. A.W.W.A. Specifications call for at least 99 per cent of the carbon to pass a 100 sieve and at least 95 per cent to pass a 200 sieve. Purchase of the material on an "as is" basis by water works is illy-advised, unless the buyer has been able to obtain an absolute commitment from some concern to grind it down. No firm not having prior experience in grinding carbon can be depended upon to produce a final product having the necessary fineness.

Further, it should be noted that the density of the material is such as to cause it to settle out of water more quickly than the usual run of water purification carbon.

On the laboratory basis the U.S.P.H.S. report indicates that the C.W.S. carbon has about half the odor-removing efficiency of good grade water purification carbon. Bearing in mind the low dispersability and rapid settling rate of the C.W.S. carbon, it appears to experienced men in the activated carbon field that its odor-removing value on a plant scale would be one-fourth to one-third the value of good water purification carbon. On the carload basis of $100 per ton for commercial water purification carbon, the C.W.S. material, if reground and packaged prior to sale, has a value in water treatment of $50 per ton on a *laboratory* test basis, but only $25 to $33 per ton on an evident *plant efficiency basis*.

In the light of the present available information, the surplus gas-mask carbon can be used in water purification *only* if it has been reground to size in accordance with current practice in the field and then may be expected to require the use of three to four times as much material as the commercially available carbon.

It also appears that, in terms of odor removal value in water treatment, the water utility would not be justified in purchasing the material (after it has been ground to proper size) at a price in excess of $25 per ton.

HARRY E. JORDAN
Secretary

A Study of C.W.S. Activated Carbons

THE question of the suitability of surplus Chemical Warfare Service activated carbons, that had been impregnated with silver and copper, for possible use in the treatment of public water supplies was referred to this station. Large quantities of these materials were available, and if it could be shown that there was no risk to the health of the water consumer, surplus stocks could well be used for taste and odor control in water treatment. The purpose of this report is to describe the experiments made to determine the suitability of some Chemical Warfare Service carbons and to make suitable recommendation for their use.

Four samples of activated carbon have been received from the C.W.S. and have been arbitrarily designated at our laboratory as A, B, C and D. Sample D was received Oct. 25, 1944, from the C.W.S. laboratory at Columbus, Ohio, and as received, was labeled "Whetlerite activated carbon type A S." Samples A, B and C were received Nov. 8, 1944, from the C.W.S. warehouse at Lawrence, Mass. The corresponding labels on these were as follows:

A—activated charcoal 6/20 sieve
B—activated charcoal 12/20 sieve
D_2W_7
C—activated charcoal 12/30 sieve

All samples received were granulated and after careful sampling they were ground in a ball mill to pass a 200-mesh sieve before they were analyzed or tested for water treatment characteristics.

A qualitative analysis on the four samples made by conventional methods indicated the results shown in Table 1.

TABLE 1

Sample	Cations Found Present
A	Copper, Iron, Aluminum, Calcium—trace
B	Copper, Iron, Aluminum, Barium—trace, Calcium—trace
C	Copper, Iron, Aluminum, Calcium—trace
D	Silver, Copper, Iron, Aluminum, Calcium—trace

These cations, with the exception of calcium and barium, were determined quantitatively. The results obtained are shown in Table 2.

TABLE 2

Sample A		Sample B	
Mineral	*Percentage*	Mineral	*Percentage*
Copper	9.07	Copper	7.43
Iron	5.0	Iron	4.34
Aluminum	0.62	Aluminum	0.11
Sample C		**Sample D**	
Mineral	*Percentage*	Mineral	*Percentage*
Copper	8.57	Copper	7.65
Iron	3.11	Silver	0.09
Aluminum	0.41	Iron	0.31
		Aluminum	0.32

Water Treatment Experiment

Experiments on water were conducted, using sample "D," to determine the efficiency of the carbon in water treatment, and the amount of copper recovered from the treated water at various time intervals, using varying amounts of carbon in waters of pH values varying over the range ordinarily considered suitable for drinking purposes.

It was found that the silver present in the Whetlerite carbon was insoluble, negative tests for silver being obtained after a two-hour contact period in waters varying in pH from 4.1 to 10.0. Also a suspension of 10,000 ppm. of the carbon in distilled water at pH 7.15 stood in the laboratory for three weeks without any silver dissolving in the water.

A preliminary experiment was conducted to determine the amount of copper washed out of the carbon when used to treat water. Carbon was used in concentrations varying from 250 to 2,000 ppm.

Samples were agitated continuously for one hour, after which samples were filtered off and copper determined on the filtrate colorimetrically, using the carbamate method (1). These waters were then allowed to stand with intermittent shaking for a period up to 24 hours. Samples were filtered off and analyzed for copper at five-, eight- and 24-hour intervals with results as shown in Table 3.

TABLE 3

Carbon Used for Treatment of Distilled H_2O—pH 6.7 *ppm.*	Solution at End of 1 Hr. *ppm. cu. in.*	Solution at End of 5 Hr. *ppm. cu. in.*	Solution at End of 8 Hr. *ppm. cu. in.*	Solution at End of 24 Hr. *ppm. cu. in.*
250	0.040	0.060	0.030	0.010
500	0.020	0.040	0.010	0.010
1000	0.020	0.020	0.010	0.010
2000	0.010	0.010	0.010	0.010

TABLE 4

Amount of Carbon Used for 2-hr. Contact Period *ppm.*	Copper Recovered From Water, *ppm.*							
	pH 5.0	pH 6.0	pH 6.5	pH 7.0	pH 8.0	pH 8.5	pH 9.0	pH 10.0
20	1.0	0.60	0.40	0.14	0.08	0.14	0.04	0.04
40	2.0	0.70	0.40	0.10	0.06	0.10	0.02	0.04
60	3.0	0.80	0.10	0.04	0.06	0.06	0.02	0.02
80	4.0	0.60	0.10	0.04	0.40	0.10	0.02	0.01

TABLE 5

Amount of Carbon Used for 2-hr. Contact Period *ppm.*	Percentage of Total Copper Present in Carbon Which Goes Into Solution in Water at Various pH Values							
	pH 5.0	pH 6.0	pH 6.5	pH 7.0	pH 8.0	pH 8.5	pH 9.0	pH 10.0
20	65	39.2	26.1	9.2	5.2	9.2	2.6	2.6
40	65	22.9	13.1	3.3	2.0	3.3	0.7	1.3
60	65	17.4	2.2	0.9	1.3	1.3	0.4	0.4
80	65	9.8	1.6	0.7	6.5	1.6	0.3	0.2

TABLE 6

pH of Water Treated	Copper Recovered From Water Treated With 60 ppm. Carbon at End of Following Periods *ppm.*						
	1 hr.	2 hr.	3 hr.	5 hr.	6 hr.	7 hr.	24 hr.
5.0	3.0	3.0	4.0	4.6	4.6	4.6	4.6
5.75	2.0	2.6	3.0	3.0	3.0	3.0	4.0
6.75	0.9	1.0	1.4	1.4	1.0	1.0	1.4
7.85	0.5	0.5	0.6	0.7	0.5	0.5	0.5
9.10	0.06	0.16	0.5	0.3	0.2	0.1	0.1

TABLE 7

pH of Water Treated	Effect of Time on Percentage of Total Copper Present in Carbon Which Goes Into Solution in Water at Various pH's With Intermittent Agitation. *percentage*						
	1 hr.	2 hr.	3 hr.	5 hr.	6 hr.	7 hr.	24 hr.
5.0	65	65	87	100	100	100	100
5.75	43	57	65	65	65	65	87
6.75	20	22	30	30	22	22	30
7.85	11	11	13	15	11	11	11
9.10	1.3	3.5	11	6.5	4.3	2.2	2.2

From these results it is apparent that the concentrations of copper obtained in a water around the neutral point when treated with concentrations of impregnated carbons up to 2,000 ppm. for periods up to 24 hours are not significant.

It was then decided to use smaller amounts of carbon in the water treatment. A series of waters buffered at pH values of from 5.0 to 10.0 were set up with amounts of carbon varying from 20 to 80 ppm. These were agitated continuously for two hours. At the end of the agitation period the water was filtered off and copper determined colorimetrically on the filtrate. The results are given in Tables 4 and 5.

A series of waters was buffered at varying pH values from 5.0 to 9.1 and treated with 60 ppm. of sample "D," varying the time of contact from one hour up to 24 hours.

Copper was determined colorimetrically on water filtered off at these various time intervals. Agitation was intermittent, samples being shaken at approximately 30-minute intervals up to the seven-hour period and then not agitated at all from the seven- to 24-hour period. The results of this series are given in Tables 6 and 7.

With continuous agitation, less copper seemed to dissolve out of the carbon than with only intermittent agitation or standing. This was probably due to a readsorption of the copper which at one time did go into solution. The solubility of the copper decidedly decreased with increase of pH and when it is considered that potable waters are usually on the alkaline side rather than acid, the amount of copper dissolving in the water from any amount of carbon used in treatment would be considerably less than the permissible 3.0 ppm.

In neutral and slightly alkaline waters, there seemed to be a tendency for the amount of copper dissolving to vary inversely with the amount of carbon used, higher doses of carbon yielding lower percentages of copper going into solution.

Phenol Value

The phenol value of an activated carbon is defined (2) as the quantity of carbon in milligrams required to remove 90 per cent of the phenol from a liter of distilled water containing 100 ppb. (0.100 ppm.) of phenol in an hour contact period at 20° to 25°C. with a given speed of mixing. A standard phenol solution containing 100 ppb. was made up in distilled water. Liter quantities of this solution were treated with varying amounts of each carbon sample for a two-hour contact period.* The treated solutions were then filtered and phenol determined on the filtrate colorimetrically by the Gibbs method, using 2–6 dibromoquinone-chloroimide as an indicator. The results were plotted on a curve and the phenol values were determined graphically. The phenol values determined in this way on samples of the four carbons ground to pass 200 mesh were as shown in Table 8.

TABLE 8

Phenol Value

Sample	
A	45
B	54
C	44
D	102

* The two-hour period was adopted from Baylis (3) before it was learned that a one-hour period was specified by the A.W.W.A. committee. This increased contact period might help the phenol value somewhat but we do not consider the possible divergence important enough to call for a repetition of the phenol value tests.

The A.W.W.A. committee report on activated carbons states (2): "A phenol value of thirty (30) shall be considered as the upper specification limit for activated carbons classified as water purification grade, and values above this figure shall constitute cause for rejection." On the basis of the above results, therefore, it must be concluded: (1) that none of these carbons is satisfactory in phenol value when ground to pass 200 mesh, and (2) that sample "D" is the poorest of the lot.

Odor Removal Tests

Some experiments were run, using sample "D" to determine the effectiveness on odor removal as compared to Nuchar C-115, a good grade of activated carbon for use in water treatment. Ohio River water of Nov. 14, 1944, having an odor of pO-3, was treated with varying amounts of sample "D" and the same amounts of Nuchar C-115 for one hour. Odor was then determined and the comparisons are given in Table 9.

TABLE 9

Carbon Used for Treatment *ppm.*	pO After 1 hr. Treatment With Nuchar	pO After 1 hr. Treatment With "D"
0	3	3
20	1	2
40	1	1
60	1	1
80	0	1

Butadiene waste solutions were made up in concentrations of 0.5 per cent waste and 1.0 per cent waste. These solutions were treated with sample "D" and Nuchar C-115 to obtain a comparison of the effectiveness of the two types of carbon. The contact period was for one hour, as in the case of the Ohio River water treatment above. The results of these experiments are shown in the following Tables 10 and 11. These data on odor removal indicate that it takes at least twice the quantity of sample "D" to accomplish the same result in odor reduction as a good grade of commercial activated carbon.

TABLE 10

Treatment of 0.5% Butadiene Waste Solution

Carbon Used for Treatment *ppm.*	pO After 1 hr. Treatment With Nuchar	pO After 1 hr. Treatment With "D"
0	3	3
20	No odor present	0
40	No odor present	0
60	No odor present	No odor present
80	No odor present	No odor present

TABLE 11

Treatment of 1.0% Butadiene Waste Solution

Carbon Used *ppm.*	pO After 1 hr. With Nuchar	pO After 1 hr. With "D"
0	3	3
20	0	1
40	0	1
60	0	0
80	0	0

Summary

Tests were run on four samples of granular activated carbon obtained from the Chemical Warfare Service. Analysis of these carbons indicated that copper and silver were the only objectionable elements contained in them. Only one sample contained any silver and it was in a form which remained insoluble in the entire pH range en-

countered in treatment of potable waters. The copper content of these samples ranged from 7.43 to 9.07 per cent. Because of the similarity of the copper content of the four samples, the solubility of the copper on only one sample was studied. The results of these studies indicated that for waters between pH 6.0 and 10.0, negligible amounts of copper went into solution, and the copper becomes less soluble the longer the contact period, the greater the agitation and the larger the dose of carbon used. This is apparently due to a readsorption of the copper onto the carbon. On the basis of these tests very high limits of carbon doses may be used on waters of pH from 6.5 up, where agitation is good, and doses up to 50 ppm. of carbon may be used on waters of lower pH's and poor agitation before the copper content of the treated water materially exceeds the permissible 3.0 ppm.

Samples of these carbons ground to pass 200 mesh were tested for phenol value and odor removal ability. Their phenol values were all over 30 and their odor removal performance compared unfavorably with a good grade of commercial powdered activated carbon. It is concluded, therefore, that all of these carbons are unsatisfactory for activated carbons classified as of water purification grade upon the basis of phenol and odor removing performance, rather than for any additional hazard that they might introduce because of the silver or copper that they contain.

This study has shown that there is no danger of imparting toxic concentrations of silver or copper to water by treatment with these carbons. It is recommended that the use of Chemical Warfare Service activated carbons containing 0.1 per cent silver and up to 10 per cent copper be permitted for the treatment of public water supplies.

References

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